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Relationship Between Hydrologic Regimes, Channel Morphology, and Vegetation Successional Processes

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FINAL REPORT

RELATIONSHIPS BETWEEN HYDROLOGIC REGIMES, CHANNEL MORPHOLOGY, AND VEGETATION SUCCESSIONAL PROCESSES

by

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Abstract

Riparian ecosystems compose < 1-2% of the semi-arid west. Stream incision lowers the water tables which support riparian vegetation leading to a loss riparian habitat. Incision has dominated fluvial processes in the central Nevada mountains for the past 200-300 years. The rate of this incision may be affected by side valley alluvial fans.

In 1998 multivariate analysis of channel incision since 1995 against geomorphic and vegetative characteristics showed that narrower, deeper channels with less bank vegetation, more willows on the lowest terrace, and more sorted channel beds experienced greater incision. In 1999 channel cross sections above, at and below alluvial fans were analyzed using discriminant analysis. The at fan cross sections had characteristics similar to the more incised sites from the 1998 data. This indicates that alluvial fans affected the rate of stream incision and should be addressed in future management of riparian areas.

Keywords: Alluvial fans, stream incision, riparian vegetation, and discriminant analysis

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Introduction

Riparian systems represent approximately 1-2 % of the Great Basin by area, but receive a disproportionate amount of use by wildlife, recreationalists, ranchers and other land-users. In arid and semi-arid lands riparian systems are extremely important and further loss of riparian habitat is of great concern to land managers. These systems are dynamic and their rate and magnitude of change reflect the influences of past and present geomorphic, hydrologic, ecological and anthropogenic factors. Many stream sections in the Toiyabe, Toquima, and Monitor ranges of central Nevada are currently incising (Miller et al., in press). Incision lowers the high water tables necessary to sustain riparian vegetation which then results in a loss of riparian habitat (Chambers et al., 1998).

Past and present drainage scale processes are influencing current stream incision. Central Nevada watersheds experienced a shift to warmer, drier conditions during the late Holocene which resulted in a period of hillslope erosion which lasted from about 2,500 to 1960 YBP. This erosion depleted the hillslopes of fine sediments resulting in sediment starved streams and contributing to subsequent stream incision (Miller et al., in press). Stratigraphic records show that a recent phase of incision that is significantly influencing the stream systems and riparian corridors today began about 290 YBP. The incision that began 290YBP caused the streams of the Central Nevada watersheds to cross a threshold to a state of dis-equilibrium. The threshold theory was popularized by Schumm (1973) but perhaps the most succinct definition of what a threshold is and how it affects the fluvial system is by Ritter et al. (1999). "Thresholds are most simply thought of as the boundary conditions at which a system changes from a state of equilibrium to one of disequilibrium.". Once a threshold is exceeded and the system moves to another state, it is not always possible to reverse the process.

On a more localized scale, the degree and magnitude of incision throughout the drainages varies at the stream reach level. The study drainages are characterized by side valley alluvial fans that obtained their greatest magnitude during the period of hillslope erosion 2,500 to 1,300 YBP (Chambers et al., 1998; Miller et al., in press). These alluvial fans originate in the axillary valleys and terminate on the main valley floors, often intercepting the stream channels. Incision is often greatest where the alluvial fan intercepts the channel and below the alluvial fan. There is relatively less incision above the alluvial fans. In many cases wet meadows are located immediately upstream of the fan complexes. Thus the fans are not only influencing stream incision, but also the structure of riparian plant communities.

In addition to the preliminary work done in central Nevada (Chambers et al. 1998; Miller et al. in press), the influence of alluvial fans has recently been studied in the Cascades region of Oregon (Grant and Swanson, 1995). These studies revealed a pattern of steeper valley slopes and more confined valley bottoms where alluvial fans extend into the main valley. Valley slope and width have been linked to stream power and thus susceptibility to erosion/incision (Bull, 1979; Leopold and Maddock, 1953), indicating that alluvial fans may contribute to greater localized incision of stream channels. Thus, to determine exactly what characteristics are influencing incision and how they are related to alluvial fan position quantitative analysis of the geomorphic, hydrologic and vegetative characteristics of the stream sections above, at and below alluvial fans must be examined.

The hydrologic factor most directly related to incision or erosion is stream power which is often referred to as a driving force of erosion or incision. Stream power is derived from the discharge of the stream channel (Bull, 1979). In computing stream power, it is important that one measures the stream flow or discharge that is most effective in determining channel shape. Previous work showed that a flow that occurred every 1.5 years was able to entrain bed material (Williams, 1978; Ferguson, 1987). This flow is commonly referred to as "bankfull" flow since it often reached at the first distinct break in bank slope. Discharge for the streams in our study area varies greatly year to year and, thus, the 1.5 year flow may not be the most effective flow for determining fluvial processes and forms. Previous studies in semi-arid and arid areas have found higher magnitude, less frequent flows which have the ability to entrain channel material are more effective in re-working the stream channel and floodplain morphology (Baker, 1977; Bull, 1997; Stromberg et al., 1993; Graff, 1983). These findings indicate that it is best to use several measurements of discharge to determine the flows that are responsible for the most of the recent channel incision.

The geomorphic characteristics of stream banks and channels most associated with resistance to erosion/incision are the bank and channel substrate materials. The maximum size (D84), median size (D50), and grain size distribution largely determine a channels susceptibility to erosion and/or incision. Particle size is used in the Sheild's equation to determine the critical shear needed to entrain bed material. The estimated critical force is then compared to the actual force exerted at a given flow. The relationship between channel stability and the Shields equation and other equations that estimate tractive forces has been determined in laboratory and field tests (Ergenzinger and Christaller, 1994; Hey and Thorne, 1986; Knighton, 1984; Komar, 1987; Leopold et al., 1964; Komar and Shih, 1992; Olsen et al., 1997). The size distribution of bed material also relates to ease of entrainment. A greater force is necessary to entrain the larger (D84) particle when all particles are of a similar size (Komar, 1987). When there is a greater difference in size clasts it is thought that a lesser force is necessary to move the large (D84) particles and a greater force is necessary to move the smaller particles. Also, the percentage of silt and clay in the banks can influence channel stability and patterns of incision and erosion (Schumm and Khan, 1972).

Vegetation characteristics (species and relative abundance) can significantly influence stream bank and channel bottom stability. In a study of four small streams in southwestern Australia, dense stream bank vegetation contributed to narrower channels (Nanson and Huang, 1997). Preliminary analysis of vegetation characteristics of existing stream transects in our study drainages showed that biomass of graminoids, biomass of perennial forbs, and height, size, and number of willow clumps best correspond to degree of erosion/incision (Martin, unpublished). While vegetation exerts an influence on stream channels, riparian vegetation is also controlled by fluvial processes. The fluvial system provides riparian vegetation with higher soil moisture, a supply of sediment, and a buffer from extreme temperatures, and water table fluctuations. It also creates a local environment with frequent physical disturbances of various magnitudes (Naiman and Decamps, 1997). Riparian species have adjusted to such disturbances in their life history strategies. Measuring channel geomorphology and hydrology along with vegetation frequency, density and abundance can provide the information needed to link stream dynamics and vegetation community dynamics (Hupp and Osterkamp, 1985; Hupp, 1992; Scott et al., 1996).

Additional factors that may contribute to the degree of incision at a site are the proximity of roads to the stream channel and other human induced disturbances such as mining and grazing. Trimble (1995) found that stream bank stability is directly reduced by the mechanical action of trampling by cattle. Stream captures by roads have been linked to progressive upstream incision (Galay, 1983). Historical aerial photos and previous investigations document that several streams have captured roads in drainages of our study area and that where this occurred increased incision resulted.

An understanding of stream hydrology, channel morphology, substrate characteristics and riparian vegetation composition and structure is necessary to explain incision at the stream reach scale. Large scale geomorphic features, such as side valley alluvial fans, may have both direct and indirect effects on channel characteristics and vegetation. Few studies have quantified all the above characteristics in one analysis (Table 1). An examination of both reach scale and larger scale factors is necessary to discern how the various factors affect each other and whether they are a result of past incision or could contribute to future incision. The specific objectives of this study were to: 1) establish the geomorphic, hydrologic, and vegetative factors that influence incising stream sections; 2) determine the relationships among the variables that contribute to local stream incision; 3) determine the effects of alluvial fans, channel geomorphology, stream substrate characteristics and local hydrology on the composition and structure of riparian vegetation; and 4) use knowledge of the whole system to identify which geomorphic, hydrologic and vegetative characteristics resulted from past incision and which are contributing to present or future incision. The first Component (conducted in 1998), examines the relationships among recent stream incision, channel morphology, channel substrate, and riparian vegetation. The second Component (conducted in 1999), concentrates on how alluvial fan position corresponds to the relationships found in the first Component. The findings from both Components and the knowledge of larger scale geomorphic processes combine to explain the overall susceptibility of a particular stream reach to short term incision and the effect of this incision on riparian vegetation composition and structure.

Methods

Site Description

The study drainages are located in the Toiyabe, Toquima, and Monitor ranges of central Nevada on the Humbolt-Toiyabe National forest (Figure 1). Drainage elevations range from about 1900 m at the base of the drainages where streams flow into broad central valleys to 2438 meters at the highest elevations. Lithology includes limestone, granitic, and volcanic rock. Most precipitation (60%) is received during the winter and spring as snow, with a few summer thundershowers. The majority of stream flow is from snowmelt runoff between April and July. All streams are perennial with low flows of about 0.0057 to 0.0567 cubic meters per second (cms) (Hess and Bohman, 1996). High flows among drainages ranged from 0.135 to 1.19 cms when measured in June of 1998 using the procedure outlined in Harrelson et al. (1994).

Drainages in the study area are characterized by steep longitudinal gradients and steep confining hillslopes. Water surface slope, measured with a stadia rod and level in June, 1998, ranged from 0.04 % to 0.21 %. Interspersed throughout the drainages are side valley alluvial fans that formed from 1960 to 2500 YBP (Miller et al., in press). Where alluvial fans extend across the valley bottoms, the streams are more confined, the longitudinal gradient is increased, and the soil material is generally coarser. The stream channels exhibit some degree of entrenchment in most reaches, the greatest being at the alluvial fans and, in general, the least being upstream of (above) the alluvial fans. Where entrenchment is 1 meter or more, the riparian communities are confined to the entrenched area. The dominant riparian vegetation throughout the drainages includes aspen, birch, and especially warm willow types (Weixelman et al., 1996). Meadow types are found immediately upstream of alluvial fans and are characterized by lower stream and valley gradients and finer textured soils. At and below the alluvial fans the warm willow type dominates with birch or aspen occurring less frequently. The warm willow type is also found above alluvial fans that lack meadows.

Study Design

The first Component of this study was conducted during the 1998 field season. The main emphasis was to examine the relationship between recent incision and the geomorphic, hydrologic and vegetative factors at individual study reaches. Sites were selected on the basis of vegetation type, stream channel morphology, absence of road or other structural influences, and presence of inset terraces. All sites were within the warm willow vegetation type, had a single channel, and exhibited similar fluvial processes. Inset terraces were the result of incision which occurred in 1975 and 1984 (Chambers et al., 1998) and were used as a benchmark from which to measure incision since 1984 or 1975.

In 1995, 10 long-term monitoring sites were established in the warm willow vegetation type at or below alluvial fans as part of the larger Ecosystem Management Project. Three permanent stream cross sections were located within each site (n=30). These sites were chosen primarily because of the presence of inset terraces which dated to 1984 or 1975 and which provided a benchmark of incision since that time. Fourteen original cross sections spread over 5 sites were suitable for use in this study, and were used to provide data on stream incision that occurred between 1995 and 1998. Sites that had been influenced by road captures, blockages or beaver dams were not included. To increase the sample size, 6 more sites were added with 3 and 4 cross sections each for a total of 43 cross sections at 11 sites. These occur in 9 drainages (Table 2; Figure 1). The reach lengths of the study sites were determined in the field by observing breaks in channel slope, form and substrate material and ranged from 15 to 30 m in length. The three cross sections were systematically located within each reach using uniform spacing. Two to

4 vegetation transects were clustered within 3 meters of each cross section for a total of 10 vegetation transects per site.

The second Component of the study was conducted during the 1999 field season and was structured to characterize entire fan systems. Fan systems with and without meadows were included since both the vegetation and geomorphic features of the two types differ. To determine the relationships between alluvial fan position, stream channel incision and riparian vegetation structure and composition, transects were placed upstream (above) the fans, at the fans, and downstream (below) the fans. Alluvial fan complexes were chosen that intersected the stream channel and that exhibited minimal influences from roads, rock outcroppings or other obstructions. For fans without meadows (n=5), one transect was located > 50 m below the fan. Three transects were located at the fan, (upper edge, middle and lower edge). Also, one transect was placed above the fan again at > 50 m. For these fans there were a total of 5 above fan cross sections, 16 at fan cross sections and 4 below fan cross sections. For fan systems with meadows (n=5), one transect was placed below the fan, three at the fan, one > 50 m above the fan, and the remaining three to five were spaced out through the meadow for a total of seven to nine transects. All but the meadow cross sections were subject to the same criteria as for the fan complexes without meadows. Distances between meadow cross sections depended on the length of the meadow. There were a total of 20 above fan cross sections, 15 at fan cross sections and 3 below fan cross sections. If there were obstructions such as roads or rocks for certain a fan position, a cross section was not placed there, thus, accounting for the lower number of below fan cross sections. In total there were 62 transects in 9 drainages in the Toiyabe, Toquima, and Monitor ranges, (Table 3; Figure 1). For vegetation sampling there were three vegetation transects for each cross section: one a meter upstream, one a meter downstream, and one at the cross-section.

Field Methods:

Geomorphic data: For the first Component cross sectional profiles were collected for all 43 stream cross sections in August of 1998. Permanently located end points for the transects were set on the highest surface or valley floor. Using a "TopCon" total station, each significant geomorphic feature was recorded from one side of the entrenched stream system to the opposite side. Cross sections were identified using the drainage name, position in the drainage, and the order of transects from the upstream to downstream transects (Table 2). The main geomorphic features recorded in1998 were high flow depth and width, channel thalweg, bankfull depth and width, height of first terrace, and depth from valley floor (Figure 2). The high water level for 1998 was identified in the field from observing debris left from the high flow in 1998. The bankfull level was determined by the first distinct break in channel bank slope. The first terrace was the first major surface above the bankfull channel. The depth from the valley floor to the channel thalweg was a measure of entrenchment or long term incision over the past 200-300 years.

Channel and bank particle size data were collected at the same time as the cross sectional data. A 100 foot modified Wolman pebble count transect was conducted through the center of each site (Harrelson et al., 1994). Only one transect was performed per site since cross sections were often too close to allow for separate transects and substrate material varied little among the cross sections. Pebbles were taken from the thalweg and either side of the thalweg. For particles up to 128 mm diameter, size was determined using a template (gravelometer) according to size categories; for particles greater than 128 mm diameter, dimensions of the longest and perpendicular axes were measured. For channel bank material a 1 liter composite sample of 3 separate soil cores was collected at each site. The channel bank was defined as the area below the first distinct break in bank slope. Percentage coarse fragments (> 2mm) was determined by sieving. Material finer than 2mm size was sent to the University of Utah Soil Testing Lab, and the percent sand, silt and clay was determined using the hydrometer method (Gee and Bauder, 1982). Both channel and bank particle sizes greater than 50%, 65% and 84% of the total particle material were determined using the methods outlined in Wolman (1957). These particle sizes are referred to as the D50, D65 and D84 particle sizes, respectively.

For the second Component of the study, the same methods were used to sample stream cross sections in July of 1999. All cross sections extended from the valley floor surface across the entrenched channel, and were named according to drainage, position in the drainage, vegetation type and order upstream to downstream (Table 3). The only difference in geomorphic sampling for 1999 was that the high flow was measured directly in June of 1999 using the method outlined in Harrelson et al. (1994); thus, it was not necessary to estimate the high flow from past debris. Both the stream channel and bank materials were sampled as in 1998. However, since the distance between transects was greater for the second Component of the study, Wolman pebble count transects and bank samples were collected for each transect individually.

Hydrologic data: In June of 1998 stream velocities were measured at each stream cross section using a Price velocity meter. Velocity readings were taken at 11-15 points across the channel so that no reading accounted for more than 10% of the channel flow area. Measurements were taken at 0.6 times the total depth, since this is where the average velocity is typically encountered in streams less than 2 meters deep (Harrelson et al., 1994). The longitudinal slope of the water surface through the cross section was measured using a surveying level and stadia rod. Due to access problems in 1998, stream velocity was measured at or near peak flow for only 38 of the 43 transects. These measurements were used to calculate the following hydrologic parameters: discharge, discharge per unit width, depth of flow, area of flow and width of flow.

These measures will be referred to as "measured peak" flow to distinguish them from measures at "bankfull" or "high flow". Most streams were close to the peak flow when velocity measurements were taken however, residual debris indicated the flow was higher for some streams before velocity measurements were taken. Thus a measure of channel area, depth and width from the debris was estimated and termed "high flow" for 1998. Bankfull flow area, depth and width was determined in the field by identifying the first distinct break in the slope of the channel banks (Figure 2).

For the second Component of the study, stream velocity and water surface slope were measured at peak flow for all 62 cross sections in May-June of 1999. Bankfull flow was identified as in 1998. The hydrologic parameters, discharge, discharge per unit width, area, depth and width, were derived for the measured peak flow and bankfull as in 1998.

Vegetation data: For the first Component of the study, herbaceous vegetation, basal and aerial cover were sampled in August of 1998. Three to 4 vegetation transects were clustered around each cross section. Transects were oriented perpendicular to the stream and parallel to cross sections. Sampling plots were located 0, 1 and 2 meters from the first distinct break in bank slope. For each transect, the sample number was 6-8 for the plots at 0 and 1 meter from the banks. If the plot at two meters was outside of the incised channel, the vegetation was not sampled. Thus, the sample number for the plots at 2 meter from the banks was lower (2-6). Frequency of herbaceous species was determined from the nested rooted frequency method using a nested plot frame in which the smallest plot size is 0.01 m^2, the second smallest is 0.04 m^2, the third smallest is 0.07 m^2 and the largest is 0.1 m^2 (Weixelman et al., 1996). A 10 point frame was used to determine basal cover of bareground, litter, rock, gravel, moss, vegetation, cow dung, or water (Chambers, 1983). In addition, percentage aerial cover was estimated from 35 mm slides taken at approximately 1 meter above the ground and projected onto a one-hundred square grid

(Chambers, 1983). Stem diameter, height, density, and size distribution of the willows were sampled in 1 m square plots in the same locations as the herbaceous vegetation sampling plots. For density of willows and other clonal species, individual stems were estimated and placed in categories: 1=(1-10), 2=(11-25), 3=(26-50), 4=(51-100), 5=(101-150), 6=(150+). To characterize the size distribution of willows, the percentage of stems in the minimum, intermediate and maximum size range was recorded, and the largest and smallest absolute stem heights and diameters were recorded. Other shrub species were recorded as present/absent only. Identical sampling was conducted for the second Component of the study, but willow data were not re-sampled for transects used in the first Component of the study.

Data Preparation

Geomorphic/hydrologic data: Measures of channel morphology and flow used for the first Component were channel area, depth, width, width/depth ratio, discharge and discharge per unit width. For our study sites the flow which exerts the most influence on the channel may not be the bankfull flow but could be a higher magnitude, less frequent flow. Both bankfull and higher flow depths have been used in previous studies (Williams, 1978; Stromberg and Patten, 1991). For the 14 transects for which there were data back to 1995, percentage channel area change was calculated by dividing the area of the channel in 1998 minus the area of the channel in 1995 by the area of the channel in 1998. This was done for "measured peak", bankfull and highflow channel areas. A positive value indicated that the channel was larger in 1998 than 1995 and erosion had occurred. A negative value indicated that the channel area was smaller in 1998 and aggradation had occurred. The same method was used for calculating depth change or incision from 1995 to 1998. By taking a percentage of channel area change, streams of different sizes and flows could be compared. In addition to channel morphology, a measure of "entrenchment" was calculated.

This was the depth of the bankfull channel over the depth of the channel from the valley floor to the channel thalweg.

For the second Component cross sections were read for 1999 only and there were no measures of past channel morphology. The same channel morphological characteristics were compiled for the 1999 data except since the actual peak flow was measured in June of 1999 high flow did not need to be estimated. A measurement of entrenchment was also included. Since fan position was the dependent variable in the second Component, two additional statistics were computed to relativize the influence of different drainages on the influence of fan position. The "depth from valley floor" for each transect in a fan system was divided by the deepest "depth from valley floor" for an entire fan complex giving a relative depth from the valley floor for each cross section in a fan complex. The "entrenchment" statistic, which takes the depth bankfull/depth from valley floor for a particular cross section was also relativized in the same manner to give an idea of the where entrenchment was greatest throughout each fan complex (Figure 3). These statistics were used to characterize the difference in degree of incision and entrenchment for transects at, above and below alluvial fans.

For the 1998 particle size data, I used the raw data for D50, D65 and D84 for channels and banks as well as the percentage silt-clay of the bank material. In addition I formulated a statistic designed to represent the degree of "sorting". It is recognized that if the difference between the D50 and D84 is small, a greater force is necessary to move the particles (Bathurst et al., 1987; Olsen et al., 1997;Yang, 1996; Meyer-Peter and Mueller, 1948). Sorting can also indicate higher past forces acted on the channel. Thus, D50 to D84 ratios for both the channel and stream bank were used in the analyses.

The relationship between the driving forces, as measured from channel flow and slope, and the resistive properties of the channel, represented by D50, D65, D84, and measures of particle size distribution, can be used to predict the tendency of a stream or river to incise or agrade (Bathurst et al., 1987; Olsen et al., 1997). This balance of forces can be represented by the Shield's critical shear equation or the critical discharge shown below:

Equation 1) Shield's critical shear = $\theta * (2.65-1) * g * D_i$ (Komar, 1987)

θ is a set value or calculated depending on d84/d50 ratio.

(2.65-1) is the particle density minus the density of water in g/cm^3

g= gravity (981 cm/s^2)

D_i = the particle diameter in cm^2

Equation 2) Critical discharge = $0.15 * (g^{.5}) * ((D_i/100)^{1.5}) * (S^{-1.12})$ (Bathurst et al., 1987)

g= gravity (9.81 m/s^2)

D_i = the particle diameter in cm^2

S= slope of the water surface in percent

In 1998 I used θ values of .04, .06 and a variable θ calculated from the below equation:

Equation 3) $\theta = 0.0834 * (D_{84}/D_{50})^{-.872}$

This equation was used for θ values down to 0.02, if the calculated θ value fell below 0.02, the set value of 0.02 was used (Andrews, 1984). In 1999 only the variable θ value from equation 3 was used in the sheied's equation. This was done both for the D50, D65 and D84 particle sizes of the channels and banks in 1998 and 1999. The actual shear stress exerted on the channel was calculated from the slope of the water profile, force of gravity and density and thalweg depth at "measured peak" using the equation:

Equation 5) Actual shear = g * D * S (Bull, 1979)

g= density of water (1 for pure water) * gravity 981cm/s^2

D= thalweg depth in cm

S= slope of water surface in percent

Actual discharge is represented by discharge per unit width which was just the discharge/width of channel at "measured peak". To show the relationship between erosive and resistive forces, I took the critical shear statistics over the actual shear stress statistics, and the critical discharge statistics over the actual discharge statistics.

Vegetation: The vegetation transects for both the 1998 and 1999 data were averaged so that the sample number for vegetation data equaled that for geomorphic data. Only the nested rooted frequency data from the 0.04 m^2 plot sizes was used. This size was chosen because it best represented species occurrence throughout the sites. Willow density, size distribution, maximum stem height and maximum stem diameter were used in the analyses. Willow species were grouped by growth characteristics. *Salix boothii, Salix lutea* and *Salix lutea* x *boothii,* which grow in bunches or clusters were combined and termed "bunch willows". *Salix exigua*, which does not form bunches, was kept separate. Other shrubs were separated into riparian and upland species and were included as a presence/absence statistic. Basal and aerial cover were reported as percentages of total area. Statistics for 1999 were compiled in the same manner. In addition the frequency of *Carex nebrascensis* and *Cicuta douglasii* were used as individual statistics because of their importance in association with fan position. Vegetation species were categorized according to lifeform, (annual forb, perennial forb, annual graminoid, perennial graminoid, shrub, and tree). Species were also grouped according to wetland status using the Jurisdictional wetlands guideline

(USDA Wetland Committee, 1989) which rates plant according to their preference for wet areas, or dry upland areas. Species were placed in three categories those that occurred in wet areas were rated “wet”. Plants that could grow in wet or upland areas were grouped as “intermediate”, and those found mostly in dry, upland areas were grouped as “upland”. This was done for vegetation at 0 and 1 meter from the banks separately for fans with meadows and fans without meadows (Appendix 5, 6, 7 and 8).

Statistical Analysis

First Component - Geomorphic and Vegetation Controls on Channel Incision

For the first Component multivariate analyses were used to determine the relationship between the degree of stream incision and geomorphic, hydrologic and vegetation characteristics. Since the sample size (n=14) for the incision data was small, a measure of channel morphology closely associated with the more incised channels, channel width/depth (n=38), was also used in the analysis. To determine which geomorphic, hydrologic and vegetative factors were significantly related to channel incision and/or the channel width/depth ratio two Pearson’s correlation matrices were compiled (SAS Institute, 1990). In the first matrix all data apart from species composition data were included (Appendix 2). A second matrix was compiled which included the Reciprocal Averaging (RA) axes from the nested rooted frequency data.

Regression Analysis: Significant relationships between the physical characteristics of the site and channel incision and morphology were examined using simple and multiple linear regression (SAS, 1990). Both simple and multiple linear regression display the general trend of correlation among the data points and indicate if relationships are driven by a few outlier sites or if a trend is fairly consistent throughout the data set. Once significance was identified for specific physical variables, willow stand data and aerial and basal cover data were added to multiple linear regression analyses to determine how vegetation cover and geomorphic data interacted.

Ordination and Classification Analyses: Reciprocal averaging (RA) was used to detect any continuous trends in the nested rooted frequency data (McCune and Medford, 1995). Reciprocal averaging (RA) is an indirect gradient analysis that computes eigenvalues based on weighted averages of the species composition data (Hill, 1973; Ludwig and Reynolds, 1988). Reciprocal averaging arranges plots (in this analysis cross sections equal plots) on three axes based on the similarities and differences in species composition. The trends in these axes should be related to some environmental factor. The relationship between the RA axes and the geomorphic and willow stand data was explored by using multiple linear regression analysis. Reciprocal averaging axes 1 and 2 were the dependent variables and geomorphic and willow stand data were the independent variables. Only axes 1 and 2 were used since the third axes had significantly lower eigenvalues. There were outlier cross sections in the RA data which altered the general trends. These cross sections grouped according to particular drainages. These were removed before the linear regression was conducted. The backward elimination method determined which independent variables remained in the model (Neter, 1996).

To further address the issues with outliers additional exploratory analyses were conducted. Nested rooted frequency data was analyzed using (TWINSPAN, (McCune and Medford, 1995), and cluster analysis (McCune and Medford, 1995). TWINSPAN is based upon division of sequential reciprocal averaging ordinations and separates sample locations into groups according to species abundance. Because both TWINSPAN and cluster analysis produced similar results, the TWINSPAN results were used in the remaining analyses. TWINSPAN analysis revealed several outlier groups for vegetation composition at 0, 1, and 2 meters from the stream that were consistent with the outliers found in RA.

Discriminant Analysis: Multivariate discriminant function analysis was used to relate the outlier groups, based on TWINSPAN results of species composition, to the geomorphic factors. The re-substitution and cross-validation as allocation rules were used to reclassify cross sections (Krzanowski, 1990; Lachenbruch, 1975). This was done separately for species data at 0, 1 and 2 meters from the stream banks. Discriminant analysis uses a combination of different variables to "reclassify" data. Due to the non-parametric nature of the data the quadratic function was used in the analyses. The cross validation rule is the most rigorous re-classification rule (Lachenbruch, 1975). If the cross validation rule gave no useful results the re-substitution rule, which gives more optimistic results, was employed, and this is noted in the results. The close agreement between the original groups and the reclassified groups indicates the degree to which the selected geomorphic variables explain the original groups derived from species composition (Ramsay, 1997; Weihs, 1995). The amount each geomorphic variable contributes to reclassification is also shown in the Discriminant analysis results.

Second Component - Influences of Side Valley Fans on Channel Form and Vegetation

For the second Component the objective was to determine if there were geomorphic, hydrologic or vegetation factors associated with alluvial fan position. All cross sections were placed into groups according to whether they were located 1) above fans, 2) at fans or 3) below fans. A Pearson correlation matrix was used to determine significant relationships between fan position and the geomorphic and vegetation data.

Ordination and classification: For the second Component TWINSPAN was used to group cross sections based their species composition as represented by nested rooted frequency data. TWINSPAN groups were not used directly in further analyses, but to identify important indicator species, (e.g. *Carex nebrascensis* and *Cicuta douglasii*), that were related to fan position. The frequency of these species was used in the Discriminant analyses. The wetland and lifeform categories were also included in the discriminant analyses. All the vegetation analyses were conducted separately for fans with meadows and fans without meadows. This was done so that the more subtle species composition differences between fan positions would not be obscured by the differences between meadow and non-meadow vegetation upstream of the fans.

Discriminant analysis: Discriminant function analysis was used with fan position as the original groups and selected geomorphic and vegetation variables from the correlation matrix as the reclassification variables. Analyses were run both with geomorphic and hydrologic characteristics separate from vegetation characteristics, and in combination. Since it was evident that there are physical differences between fans with meadows and fans without meadows discriminant analysis was also conducted separately for fans with meadows and fans without meadows and then for all fans data combined.

Results

First Component - Geomorphic and Vegetation Controls on Channel Incision

Geomorphic results: A primary objective was to determine the factors controlling the magnitude of recent incision within the selected study basins. The correlation analysis results between possible combinations of incision, geomorphic characteristics, cover data and willow stand characteristics are presented in Appendix 1. The strongest relationships among geomorphic variables were further explored with simple linear regression (Figures 4, 5 ,6, and 7). The percentage area change of the channel between 1995 and 1998, for the 14 channel cross sections with data back to 1995, was highly correlated with the percentage change in depth but not with the percentage change in width of the channel. This indicates that vertical incision may be more dominant in the erosional process than lateral erosion (Figure 4a). However, approximately 1/3 of the 14 cross sections showed moderate aggradation. Aggrading channels were in general wider and shallower with larger channel material. Greater channel area in 1998 versus 1995 was also associated with lower channel width to depth ratios, establishing a connection between deeper, narrower channels (as taken from the high flow channel dimensions) and greater recent erosion (Figure 4b). A positive relationship was also found between narrower, deeper channels and greater change in depth since 1995. Channel cross sections that exhibited greater depth change between 1995 and 1998, and deeper and narrower channel cross sections were better sorted as defined by a smaller difference between channel D50 and D84 (Figure 5a-c). Larger particles can actually be entrained more easily in channel beds in which there is a greater mixture of clast sizes leaving smaller more sorted channel material (Komar and Shih, 1992). This might explain why there was also a relationship between smaller channel d84 particle sizes and deeper channels (Figure 6). Channel cross sections for which incision occurred between 1995-98 correlated positively with overall channel entrenchment. Cross sections which aggraded over the sampling period had in general less overall channel entrenchment, suggesting that channels that have exhibited more long term incision may be more prone to incision over the study period (Figure 7).

Multiple linear regression of channel incision since 1995 and geomorphic data revealed additional patterns. Changes in both area and depth between 1995 and 1998 were positively correlated with measurements that reflected past incision (the degree of entrenchment and height of the lowest terrace), smaller bank particle sizes and a smaller difference between bank D50 and D84 particle sizes (Tables 4 and 5). Relationships with substrate size found in multiple linear regression results were in agreement with the results from simple linear regression. The positive relationship between depth from the valley floor, (an indicator of the total amount of incision over the past 300 years), the height of the first terrace (an indicator of incision since the high flows of 1984 and 1975) and incision between 1995 and 1998 established a connection between incision over the longer term and more recent incision. When vegetation cover data were included, channels with greater incision since 1995 were correlated positively with greater total vegetation cover and a higher density of *Salix exigua* at 2 m from the banks (Table 5). The greater cover of vegetation and higher density of willows at these sites could be related to the presence of terraces left from the 1984 and 1975 runoff events. For sites where these terraces did not form the vegetation at 2 meters from the bank was often outside the entrenched channel. Thus, a greater density of willows at 2 m from the banks could support the connection between the level of incision since 1984 or 1975, and incision since 1995.

Multiple linear regression relationships of channel geometry, i.e., depth and width/depth, were similar to those for simple linear regression (Table 4). The deeper, narrower channels were consistently related to a smaller difference between channel d50 and d84 particle sizes and smaller channel particle sizes. In addition channel depth was positively correlated with a greater height of bunch willows, greater vegetation cover, and a higher density of *Salix exigua* at 2 m from the banks (Table 5). Deeper, narrower channels were also related to lower vegetation cover at the banks possibly due the greater height above the water table making these sites less suitable for vegetation establishment (Table 5). The width to depth ratio of the channels and the degree of incision between 1995 and 1998 are not only directly related (Figure 4b), but also share many of the same predictor variables (Tables 4 and 5). Both are non-dimensional measurements and so are less affected by differences in total channel area. These measures were more sensitive in detecting relationships among drainages with different flow regimes, and produced good results in the statistical analyses.

Species relationships

Reciprocal averaging and regression analyses: For the first Component of the study RA analyses located cross sections along three axes based on trends in species composition. Each cross section is ranked numerically from lowest to highest along each axis. Cross sections ranked closer together had more similar species composition. Those ranked at opposite ends of an axis had the greatest difference in species composition. The relative importance of each axis is represented by the relative magnitude of its eigenvalues (Table 7; Appendix 5). Because the eigenvalues for axis 3 were much lower than those for axis 1 and 2 only axes 1 and 2 were used in further analyses. The RA analysis resulted in extreme axis values for cross sections from several drainages. These outliers often did not fit the general orientation of the majority of the data. Consequently these cross sections were not included in the main analyses.

Axis values from RA analysis were used directly in multiple and simple linear regression. RA axes 1 and 2 values, minus outliers, were used as the dependent variables and geomorphic characteristics and willow density were used as the independent variables. Willow density was included as it reflects an important part of plant community structure not adequately represented in the nested rooted species composition data. The significant relationships between species composition, geomorphic characteristics and willow density were not strong for the majority of sites and trends were difficult to interpret (Table 7; Appendix 5) .

Axis 1 ranked cross sections with bank vegetation composed of species such as *Deschampsia caespitosa, Poa pratensis* and *Carex spp.* higher and cross sections with species such as *Agrostis stolonifera, Cicuta douglasii* and *Senecio hydrophilus* lower. Cross sections with *Carex spp.* and other wet to mesic species also ranked higher for axis 2 while cross sections with mesic to dry species ranked lower. The geomorphic characteristics most associated with the higher ranked cross sections were 1) greater ratios of discharge needed to move the bank and channel d50 particle sizes over actual measured discharge, and 2) less entrenchment. In general, cross sections with species that ranked higher for both RA axes were associated with more stable conditions. Lower entrenchment indicates less overall incision or erosion at that channel cross section. A higher ratio of critical discharge/ actual discharge indicate a greater ability of the channel bed to resist erosion. Thus the channel cross sections that have evidence of less past incision/erosion and an indication of future resistance to incision/erosion are associated with more wet and mesic graminoid species.

Cross sections with a greater frequency of mesic graminoids at 1 meter from the ranked higher for RA axis 1 while those with upland forbs and shrubs ranked lower. Cross sections with mesic graminoids, especially *Carex nebrascensis* and *Deschampsia caespitosa,* also ranked highest for axis 2 while those with *Agropyron intermedium, Lupinus argenteus* and shrub species ranked lower. The higher ranked cross sections according to species composition related best with the following geomorphic characteristics; 1) smaller bank particle sizes, 2) a higher percentage of silt-clay in banks, 3) greater density of *Salix exigua* and, 4) shallower channels. Cross sections with species 1 m from the bank that ranked higher on axis 2 were associated with 1) lower discharge per unit width, 2) shallower, wider channels and 3) finer bank material. In general, channel cross sections with lower erosive stream power as represented by lower flow areas, spread out over wider channel bottoms with lower flows related to higher abundances of mesic graminoids. In addition there was an association between cross sections with a greater frequency of mesic graminoids species and finer bank material.

For vegetation at 2 meters plus from the banks RA axis 1 placed cross sections with *Carex lanuginosa, Deschampsia caespitosa, Equisetum spp.* and other wet to mesic species higher and cross sections with *Agropyron spp., Melilotus officinale, Chrysothamnus* spp. and other upland species lower. Again cross sections with more mesic graminoids and forbs again ranked higher for axis 2 while those with *Agropyron spp.,* upland forbs and shrubs ranked lower. Cross sections with higher RA values for axis 1 were best related to a greater percentage of silt-clay in the banks, greater bankfull area and denser bunch willows. Cross sections with species that ranked higher for RA axis 2 were associated with greater bankfull area, less entrenchment, and denser *Salix exigua* stands (Table 6 and 7; Appendix 5).

Overall the vegetation trends found in RA related cross sections with a dominance of wet and mesic species to more stable channels that experienced a lower rate of overall incision. The regression analyses results also revealed that wet to mesic graminoids were associated with cross sections with finer textured bank material and denser willows at 1 and 2 meters from the banks. The range of values for species composition and geomorphic and willow data were low, making trends between species composition and geomorphic characteristics more subtle. However, the same geomorphic characteristics such as bank particle size and degree of entrenchment were important in describing vegetation outliers. These relationships were stronger, indicating that more distinct species complexes were a result of more distinct geomorphic characteristics.

TWINSPAN and Discriminant analysis: The outlier cross sections, as determined from the TWINSPAN groups of species frequency, were related to the geomorphic characteristics of the cross sections using Discriminant function analysis. A combination of geomorphic parameters that best re-classified the cross sections into the original TWINSPAN groups were used in the model. The Wilks-Lambda multivariate statistic is used to report model significance.

Cross sections in Barley creek made up the most distinct outlier group, according to TWINSPAN analysis. Vegetation at 0, 1, and 2 meters from the bank in Barley creek was composed of *Carex lanuginosa, Conyza canadensis* and sand bar type species (Table 6). In discriminant analysis Barley cross sections separated from the other groups based on a greater depth from valley floor and smaller bank particle sizes. According to Discriminant analysis of the groups for vegetation at 0 m from the banks, 100% of the Barley Creek cross sections were placed into the original TWINSPAN groups ($F_{24, 95} = 9.62$, $p<0.0001$) (Table 8a; Figure 8). For the groups at 1 m from the banks, 75 % of the Barley cross sections were placed in the original TWINSPAN groups ($F_{18,74} =7.36$, $p< 0.0001$) (Table 8b; Figure 9). For the groups at 2 m from the banks all Barley cross sections were correctly placed in the original TWINSPAN groups using the re-substitution rule, ($F_{30, 90} = 7.82$, $p<0.0001$), while with the cross-validation rule none of the cross sections were correctly placed in the original TWINSPAN groups. Discriminant analysis indicates a significant relationship between the deeply entrenched, wide bottom, sandy channels of Barley creek and species composition. The wide channel at the bottom of the entrenched system is currently forming point bars which could be providing surfaces for sandbar species. While the dominance of *Carex lanuginosa,* for the Barley cross sections could be related to the sandy soils (Dunaway et al. 1994).

Cross sections in Kingston canyon formed a distinct outlier group but only based on species composition at 0 m from the banks. Cross sections in this group were dominated by *Phalaris arundinacea* and *Carex nebrascensis* (Table 6). Discriminant analysis placed 100% of the

Kingston cross sections back in the original TWINSPAN groups based primarily on the high percentage (> 40%) of silt-clay in the banks and the greater depth from the valley floor for these cross sections ($F_{24, 95} = 9.62$, $p<0.0001$) (Table 8a; Figure 8). The clay loam soils provide good capillary action which, in combination with higher, more consistent flows throughout the year, could be providing good conditions for the *Carex* and *Phalaris* which dominate the Kingston cross sections.

For the Big Creek cross section vegetation at 0 and 2 meters from the banks did not form distinct groups according to RA and TWINSPAN analyses. However, at 1 meter from the banks TWINSPAN did separate Big Creek cross sections based on the dominance of *Agropyron intermedium* and *Melilotus officinale* (Table 6). The difference in species composition for the Big Creek cross sections is most likely due not to channel geomorphology but to a basin wide re-seeding with the above species following a fire in 1964. Only 66.7 % of the Big Creek cross sections were placed in the original TWINSPAN groups ($F_{18,74}=7.36$, $p< 0.0001$). The main geomorphic characteristic that distinguished the Big Creek group was a smaller channel d84 particle size. (Table 8b; Figure 9).

For the lower Stoneberger cross sections species composition at the banks and 1 m from the banks did not form a distinct group according to TWINSPAN analysis. But vegetation at 2 meters from the banks did separate based on the relative abundance of upland species such as *Lupinus argenteus* and *Chrysothamnus nauseosus* (Table 6). Discriminant analysis successfully separated lower Stoneberger cross sections based on their larger channel and bank particle sizes and lower flows using the re-substitution rule ($F_{30,90} = 7.82$, $p<0.0001$). However, with the cross-validation rule none of the cross sections were correctly regrouped. The lower peak and yearly flow in Stoneberger relative to other study drainages and the gravel and cobble substrate of the floodplain might contribute to well-drained floodplain that does not provide water necessary for mesic and wet species. This would explain the dominance of more upland species away from the channel.

The results from the analysis of outlier data indicate that species composition is still related to geomorphic features particularly channel flows, substrate material and channel form. Indeed the greater divergence in species composition of the outlier groups related to more notable geomorphic characteristics. For example, the Kingston cross sections had bank silt-clay in excess of 40% which related to almost pure stands of *Phalaris arundinacea* and *Carex nebrascensis* on the banks.

Second Component - Influences of Side Valley Fans on Channel Form and Vegetation

A Pearson's correlation matrix was computed using the geomorphic factors, total aerial vegetation, basal ground cover, species frequency of key species, frequency of wetland species, frequency of upland species and willow stand data for the 1999 sampling year (Appendix 8). TWINSPAN analysis was conducted on species composition data separately for fans with meadows and fans without meadows (Appendix 9, 10, 11 and 12). TWINSPAN tended to separate groups based on drainages and not fan position (Tables 9 and10). There were some vegetation species that seemed to associate more with above fan cross sections than for at fan or below fan positions. The species separation based on fan position was clearer for fans with meadows than for fans without (Tables 9, 10; Appendix 7, 8, 9 and 10). Species identified as indicator species by the TWINSPAN analysis are noted in Tables 9 and 10. These species appeared to be sensitive to fan position and so were analyzed in the initial correlation matrix. Of the key species only *Carex nebrascensis* and *Cicuta douglasii* were found to be significantly related either to fan position or to geomorphic characteristics associated with fan position in the initial correlation matrix. These species were included in Discriminant function analysis.

Geomorphic and vegetation data that were found to be significantly related either directly or indirectly to fan position were used in Disciminant analysis. This was first done for geomorphic data only and vegetation data only (Appendix 11-16), and then in combination (Tables 11 and 12), to determine which factors best distinguished the fan position groups. The best results were found using geomorphic and vegetation variables together (Figures 11-13). Significant vegetation differences existed between fan systems with meadows and those without meadows. Due to these differences, the analysis was conducted using 3 data sets: 1) fans with meadows, 2) fans without meadows and, 3) all fans combined.

Fan systems with meadows: The Discriminant analysis results for fans with meadows had a 10.8% error rate, ($F_{22, 48} = 6.22$, $p<0.0001$) (Table 11a). This was after the Cottonwood Creek meadow cross section # 5, which skewed the data, was removed. This site was deeply incised in 1998 and now has geomorphic characteristics that are anomalous with other meadow cross sections. Above fan cross sections separated based on higher total vegetation cover, a higher frequency of wetland species, and a smaller difference in channel particle sizes (Figure 11; Table 12a). Below fan cross sections separated from fan cross sections based primarily on a greater percentage of large willows at the banks and 1 meter from the banks and a lower occurrence of wetland vegetation. Fan cross sections separated from both above fan and below fan sites primarily based on greater relative entrenchment (Figure 11; Table 12a). Overall there were only 4 mis-classifications of fan position out of 37 cross sections and these cross sections were located on the upper and lower boundaries of a fan and ended up being placed either in the above fan group or the below fan group

Fans without meadows: The Discriminant analysis results for fans without meadows had an error rate of 16% ($F_{24,22} = 6.31$, $p<0.0001$) (Table 11b). In general for fans without meadows the at fan cross sections exhibited more past incision, were currently less stable, and had a lower presence of both herbaceous species and willows than above fan cross sections. The below fan cross sections separated from the above fan cross sections based on a greater critical shear for channel d50 particles versus actual shear, greater percentage of silt-clay in the banks, lower slopes, and smaller bank d84 particles (Figure 12; Table 12b). Cross sections above fans separated from cross sections at the fan based on a greater frequency of *Carex nebrascensis* at the bank, a smaller difference between channel D50 and D84 particle sizes, less relative depth from the valley floor to the channel bottom, and a lower percentage of larger sized *Salix exigua* species at the banks. The difference between below fan and at fan cross sections is not great. Below fan cross sections differed from at fan cross sections primarily based on a smaller difference between channel D50 and D84 particle sizes, a higher frequency of *Carex nebrascensis* at the bank, less relative depth from the valley floor to the channel bottom, and a lower percentage of larger sized *Salix exigua* species at the banks (Figure 12; Table 12b). Four cross sections out of 25 were misclassified in this analysis. These were below fan cross sections which in general did not have very distinct characteristics.

All fans: The Discriminant analysis results for all fans had an error rate of 30% in identifying fan position, ($F_{8,114} = 5.31$, $p<0.0001$) (Table 11c). The distinction between fan positions is less clear when all fans were analyzed together. Most notably below fan cross sections mis-classified. The below fan cross sections from fans without meadows tended to group with the at fan cross sections. The below fan cross sections from fans with meadows grouped with above fan cross sections (Figure 13; Table 12c). Although the differences between the meadow fan and non-meadow fan cross sections overshadow some of the effects of fan position, in general, the classification results indicated less past incision, lower disturbance of the banks and floodplain, and greater vegetation cover at cross sections above fans versus cross sections at fans. The most distinct difference was the relationship between the degree of past incision and fan position (Figure 13; Table 11c). There were several above fan cross sections in the Big Creek meadow that were incorrectly grouped as at fan or below fan cross sections. These cross sections have greater slopes and lower vegetation cover than most above fan cross sections in meadows leading to the incorrect grouping. One cross section from Cottonwood meadow also grouped as an at fan cross section; this was most likely due to the extreme incision that occurred in the Cottonwood meadow in 1998.

Discussion

First Component - Geomorphic and Vegetation controls on channel incision

The results from the 1998 analyses indicate significant relationships between recently incised channels and low width to depth ratios, more sorted bed material, and smaller bank and channel bed particle sizes. Also, relationships exist among the indicators of recent incision, vegetation cover, species composition, and willow stand characteristics. To understand effects of individual variables, and the relationships among the variables, it is necessary to examine both the geomorphic processes and vegetation dynamics occurring within these systems.

Geomorphic, vegetation cover and willow data from 1998

Recent incision: Greater incision since 1995 was directly linked to greater incision during the last 200-300 years, and to incision since the most recent large runoff events (1984 and 1975).

Both simple and multiple linear regression revealed that cross sections with greater channel bed erosion between 1995 and 1998 were more likely to have smaller bank particle sizes and more sorted channel and bank material, as indicated by a lower D50/D84 ratio. In addition, a greater density of willows at 2 meters from the banks were found in channel sections with greater bed erosion since 1995. According to tree ring analysis the willows established in 1984 or 1975 after two large runoff events which provided suitable surfaces for willow establishment (Chambers et al., 1998). Thus, there is a connection between a greater density of willows and channels and floodplains that were affected by past large flow events. This relationship between measures of past incision and incision since 1995 suggests that the trend of incision is ongoing.

Relating recent erosion/incision to channel width/depth and particle size: Since there were only 14 cross sections that had data extending back to 1995, it was difficult to extrapolate trends found for those sites to the rest of the 1998 cross sections. A significant one time measure of channel morphology that may relate to channel incision was sought to expand the relationships found for channel incision between 1995 and 1998 to cross sections with data for 1998 only. One of the best correlations was between percent channel area change and the width to depth ratio of the channel measured at peak flow in June of 1998 (figure 4b). The width to depth ratio is a useful parameter not only because it related to channel incision and erosion, but also because it is a non-dimensional measure and, thus, is not directly affected by differences in overall channel area and flow.

The channel width and depth is governed initially by the discharge with both width and depth increasing with increased flow (Knighton, 1984). There is some evidence both from this study and from previous work that as stream discharge increases, channel depth relative to width may increase (Leopold and Maddock, 1953). However, the channel width to depth ratio has been mostly attributed to the channel and bank materials. Channels composed of fine sediments tend to have narrower deeper channels while those composed of coarser material tend to be wider and shallower (Schumm and Khan, 1972). Data collected here suggest that narrower, deeper channels are currently experiencing relatively greater, more concentrated flows and that these channel sections have finer textured channel and bank material. The combination of more concentrated flows and finer material make these channels more susceptible to increased incision, which increases the depth and further concentrates the flow. Thus, there is a positive feedback mechanism occurring wherein the deeper and narrower a channel becomes, the more force is concentrated on the channel bottom and the more likely it is to incise further. This could explain why channels that are currently deep and narrow exhibited greater incision over the past 300 years.

Species composition related to channel characteristics: Species composition, as represented by nested rooted frequency data taken at 0, 1, and 2 meters from the banks, could not be directly related to channel incision due to the low sample number (n< 14) with data extending back to 1995. Instead, species composition data for cross sections, minus outlier values, were regressed against the morphological characteristics of the channels, substrate sizes, and willow density. For the majority of the cross sections, mesic and wet species (*Carex* spp., *Deschampsia caespitosa* etc.) (Table 6) which normally establish and persist under wetter conditions (Weixelman et al., 1997) were associated with more stable channel cross sections. In general, these were lower flow, wider, shallower channels that had experienced less overall incision such as Marysville and Antone (Table 6, 7; Appendix 5). There could be several reasons for these associations. There is greater water availability throughout the year for bank vegetation in shallower, less incised channels. Overbank flows occur more frequently in shallower, less incised stream sections since the banks are closer to the water surface. However, the magnitude of the disturbance is low since the flows and thus the energy is spread over a large area. Other researchers have found that the magnitude and frequency of flood disturbances in combination with water table depth is the major control on species occurrence (Harris, 1987; Hupp, 1992). The more incised, deeper, narrower channels tend to have more mesic to xeric vegetation at the banks (i.e. *Achillea millefolium* and *Poa pratensis*) (Table 6 , 7; Appendix 5). This is most likely related to the isolation of plant roots from the water table and the infrequency of overbank flows. In floodplain areas of Big Creek that received less frequent over bank flows, more xeric species established (Bornette and Amaros, 1996).

Understanding the recent history of the study sites aids in understanding patterns of species occurrence. For the first Component, 14 of the cross sections were part of a permanent study for which vegetation cover and species composition data were collected back to 1994. In 1995 the central Nevada drainages experienced a large runoff event which occurred after a 9 year drought. Cover data from 1994 showed that most banks had high vegetation cover in 1994 (Chambers, personal communications, 1999). Many of these cross sections experienced significant incision between 1994 and 1995 (Martin, unpublished). Cross section data from 1998 showed that the same sites now have narrower, deeper channels that also experienced greater incision since 1995. The incision resulted in channel water levels well below the bank surface which decreased the number and abundance of wet species and total vegetation cover on the banks and floodplains. Thus, there is an effect of channel morphology and past incision on both the species composition and cover at the stream banks. Since the cover of mesic and wet vegetation, particularly graminoids on the banks, was higher for more stable channel cross sections, it could be proposed that these species increased bank stability. However, this may be coincidental with these banks having higher water tables. More vegetated banks probably do not affect vertical incision. The shallower, wider channels which have lower stream power per unit width may reduce both the rate of bank erosion and channel incision.

For the outlier sites (Barley, Kingston and Stoneberger) species composition was not related to channel width and stability. Big Creek cross sections had unique species composition, but this was most likely the result of reseeding efforts after a basin wide burn in 1964. Barley Creek has sandy-loam soils and is incised up to 3 meters below the valley floor. The incised area is wide enough that point bars and new floodplain surfaces are forming and vegetation associated with these geomorphic features is establishing. The most prevalent species is *Carex lanuginosa* which prefers sandy soils. The other species are typical of sand bars. A study on the effect of plant communities and soil textures on streambank erosion (Dunaway et al., 1994) reported particle size, species composition, and erosion data similar to that found in this study for Barley Creek. Finer sandy textured soils are related to a higher degree of past incision and it is likely that both soil texture and incision have greatly affected current species composition. However, there is no evidence that vegetation has exerted an effect on channel morphology or incision.

Kingston is a higher flow system and due to the site's location at the toe of an alluvial fan it experienced greater incision over the past 200-300 years. More recently, this site has been stable even in large events. This stability is probably related to denser stands of *Salix exigua*, and greater silt-clay in the stream banks (<40%). The combination of clay soils with high capillary action and increased soil moisture throughout the season created an environment which favored *Phalaris arundanacea* and *Carex nebrascensis*. A higher percentage of clay is thought to aid in stabilizing banks (Schumm and Khan, 1972). However, there is some evidence that very high percentages of clay reduce herbaceous plant root densities (Dunaway, 1994). Interestingly, Dunaway et al. (1994)

performed flume tests on soils in the Kingston drainage which revealed high rates of erosion. However, in the field Martin (unpublished) found that for this site channel cross sections had no bank erosion and low channel incision between 1994 and 1995. Field observations confirmed this trend of low incision between 1995 and 1998. Most likely a combination of factors including the high density of *Salix exigua,* abundance of wet graminoids, soil structure and more consistent yearly flows aid in stabilizing the banks of the Kingston site.

For Stoneberger Creek, the banks and channel are composed of gravel and cobble sized particles and discharge is lower than for other drainages, particularly later in the season. Vegetation at the banks and one meter from the banks is similar to other sites. However, at 2 meters from the banks upland species such as *Chrysothamnus nauseosus* and *Lupinus argenteus* dominate the lower Stoneberger cross sections. The lower flow throughout the season means that the floodplain is inundated less frequently. Floodplain soils are also composed of coarser material with low moisture retention. Soil moisture availability and soil substrate size have been shown to affect vegetation adjacent to streams (Castelli et al., 1999; Friedman et al., 1994; Hughes, 1997). Thus, it is likely that species composition at the lower Stoneberger site is affected by these two geomorphic features.

In summary, greater incision since 1995 is positively correlated with 1) narrower, deeper channels that have smaller channel particles and in some cases smaller bank particles, 2) more sorted bed material, 3) a greater degree of past incision, 4) less total vegetation cover at the banks, and 5) the presence of more xeric species on the banks and floodplain.

Connections between recent incision (Components 1) and fan position (Component 2)

There were greater differences in channel morphology for the fan position study in 1999. The variation between different drainages and different fan types may have obscured the effects of fan position on channel morphology. Thus, channel width, depth and area did not relate significantly to fan position. The channel width/depth ratio which is a non-dimensional parameter should be less sensitive to these differences. However, it was found that channel width to depth ratios did not relate directly to fan position either. Measures of past incision (degree of entrenchment and depth from valley floor) were relativized for the fan position Component in order to minimize differences between drainages. These statistics performed well in defining fan position and relating trends of past incision from Component 1 to fan position. Denser, larger willows were found at more incised cross sections in 1998 and at fans in 1999. The general vegetation trend of wetter species at stable, less incised channel cross sections in 1998 corresponded with the occurrence of wetter species at the above fan sites especially for fans meadows in 1999.

Component 2- Influences of side valley fans on channel form and vegetation

In this study fans were separated based on vegetation. This was a valid means of categorizing fan complexes in terms of the differences in the relationship between fan position and vegetation composition and structure. The greatest contributing variables to Factor 1 when fans with meadows and fans without meadows were analyzed separately were vegetation cover, willow stand structure, and herbaceous species composition (Table 12a,b). The contribution of vegetation was much less when all fans were analyzed together, with only aerial cover of vegetation at 1 m from the banks being significant (Table 12c). The same general geomorphic characteristics, degree of entrenchment and degree of sorting for channel material, separated fan cross sections from above fan cross sections for fan complexes with meadows and without meadows. Also, these characteristics were significant in separating above fan and fan cross sections when all fans were analyzed together. This suggests that these characteristics are not associated with the presence of wet meadows. However, there is clearly some difference in fan complexes with wet meadow vegetation that drives the occurrence of this vegetation type.

Previous work indicates that wet meadows may occur upstream of some alluvial fans because of local bedrock highs that occur at those alluvial fans. These bedrock highs cause an upwelling of the aquifer flow creating a shallower water table which is able to support wet meadow vegetation (Miller, personal communications, 1999). Thus the initial presence of wet meadows may not be related to alluvial fans or channel configuration but to subsurface bedrock features. However, the persistence of wet meadow vegetation may be related to the type of alluvial fan and its tendency to incise. Two different types of alluvial fan have been described by Miller et al. (in press), One type has channel material large enough to resist incision the other has finer channel material that is more easily entrained. Alluvial fans composed of this large bed material resist incision across the fan and are characterized by steep gradients or drops across the fan. The channel material buffers the meadow upstream from incision since the downstream incision is stopped at the alluvial fan. Channels that do not have the buffering effect of the large channel bed material are more prone to incision. This may result in the upstream incision of meadows if they are present.

Upstream of fans that are composed of large bed material the gradient is relatively less steep and the bed material is composed of finer, more evenly sized material. This material settled out in the lower gradient, lower energy sections above the fans in the past when stream channels were blocked by fan material. Thus, for fan systems with bed material large enough to resist entrainment, there is a more systematic channel geometry throughout the fan complex. Where channel sections at fans have greater slopes, larger bed material and localized incision down to the large material at the fans. Stream sections upstream of alluvial fans are characterized by lower channel slopes, finer more sorted channel material, and less incision. This is not the case for stream sections upstream of fan complexes that do not have this coarse bed material. Fans which do not have large bed material do not show consistent patterns of incision, entrenchment, channel slope or bed material (Miller et al., in press).

Results from this study indicate finer material, less incision and in some cases lower slopes occur in stream sections above or upstream of alluvial fans. In general, stream sections located at alluvial fans had more sorted channel material and, in some cases, larger channel material, greater incision and greater slopes. This would support the idea that there are consistent systematic differences in channel characteristics throughout the fan complex. These relationships were found analyzing fans with large channel material and a greater drop across the fan and those without these features. If fans had been separated based on the presence of bed material large enough to resist incision and a greater drop across the alluvial fan, the differences among fan positions might have been more distinct. Surveying work by Miller and Germanoski (personal communications 1999) showed that meadows occurred upstream of both fans with large substrate material and a greater vertical drop and fans without this large material and a lesser vertical drop.

Although meadows do occur upstream of the unarmored fans these areas are more prone to incision. There is some evidence that this occurred in Barley creek where stratigraphy of the incised banks revealed organic layers associated with meadow vegetation (Germanoski, personal communication 1999). Barley Creek has fine sandy soils throughout the fan complex. This incision through the alluvial fan may be occurring in the Cottonwood Creek meadow. A previous headcut above the alluvial fan recently extended upstream through the meadow during a high flow event in 1998, resulting in up to a meter of incision. At present the channel bed material of the fan and meadow are composed of coarser material that might limit further incision. However, most likely the water table is already below a level able to sustain the wet meadow vegetation.

The analyses preformed in this study recognized the association between alluvial fan position, substrate material, channel slope and degree of incision supporting the work conducted by Miller et al. (in press). There are examples of both fans with large channel material and steeper slopes and fans without larger channel material and lesser drops throughout the study area. Once channels become incised or entrenched flow is more concentrated in the incised channel which lead often leads to greater incision in the future. Thus, it is helpful to identify the stream reaches most prone to incision before this cycle of incision becomes established. From this work and that of Miller et al. (in press), meadows upstream of fans composed of finer more erodible material appear to be at most risk of accelerated rates of incision.

Conclusion

The results from the Component 1 analyses illustrated the connection between channel geometry, bank and channel particle sizes, riparian vegetation, and the degree of incision. Most notably, channels that were narrower and deeper with smaller, more sorted bed material experienced greater incision over the past 200-300 years and since 1984 and 1995. There was also some evidence that incised cross sections had more large willows on the first terraces but a lower frequency of wet/mesic graminoid species on the banks. In addition, there was a connection between finer bank materials and certain wet gramanoids.

Analyses for Component 2 found distinct differences between the at fan and the above fan cross sections both for fans with meadows and fans without meadows. These differences were in agreement with some aspects of the Component 1 data. In general, at fan cross sections were found to have experienced more past incision. The vegetation at these cross sections was similar to that found at the more incised cross sections in Component 1. There was a greater difference between channel D50 and D84 particle sizes. This could be due to the initial channel material at these fans which, in some cases, were composed of more mixed material with larger size clasts (Miller et al., in press). In general, cross sections above fans exhibited the same wet graminoid vegetation and lower rates of past incision characteristic of the less incised cross sections from Component 1. However, the above fan cross sections also had finer, more sorted channel material while the less incised channels from Component 1 had coarser materials.

The differences in the findings from Components 1 and 2 can most likely be explained by the theory that there are two kinds of alluvial fans. Those with coarse, unmovable material and those with finer, entrainable material. If the study had focused on separating the fans from Component 2 based on this criteria, it would be expected that stream sections at the fans without the coarse, armored beds would have geomorphic and vegetative characteristics similar to the more incised stream sections from Component 1. The stream cross sections at fans with coarse armored bed material might relate better to the less incised stream cross section from Component 1. Thus, this study was useful in first determining the local vegetation and geomorphic characteristics associated with local channel incision. There was some success in relating these characteristics to the presence of alluvial fans. Future research should focus on separating fan complexes based on how successfully the channel is armored from incision and how this armoring affects (1) the fluvial processes at work throughout the fan complex and (2) the riparian vegetation communities associated with these fan complexes. Both fan types should be monitored in the future to gain knowledge of the short term incision occurring at each fan type. This work should help land managers understand the larger features contributing to stream stability and stream incision and, thus, determine those stream reaches most immediately susceptible to accelerated incision.

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Table 1. Variables sampled in 1998 and 1999. Organized by scale and type of characteristic

Scale	**Type**	**Characteristic**
Valley	Geomorphic	Position relative to alluvial fans[*]
Stream reach	Vegetation	Density of willows
		Age/height of willows
		Frequency of herbaceous species
		Total vegetative cover (aerial and basal)
		Composition of vegetation
		Ground cover (aerial and basal)
	Channel morphology	Cross sectional profile
		Depth, width, and depth/width ratio
		Depth of incision to previous terraces
		Percent channel area, and depth change 1995-1998[†]
		Bank soil particle sizes (D50,D65, D84)
		Channel particle sizes (D50, D84)
		Bank percentage silt and clay
		Slope of water surface at measured peak
	Local Hydrology	Discharge, (measured peak)
		Stream power (measured peak)
		Actual shear stress, (measured peak)
		Critical shear stress, (using particle size data)
		Critical discharge, (using particle size data)

[*] 1999 data only

[†] 1998 data only

Table 2. The site name, code and transect numbers, location, elevation and year used for the 1998 study sites (component 1).

Site name	Site code/ transect	Latitude	Longitude	Elevation meters	Year established
Antone Upper	ATU 1-3	116° 54' 30" W	38° 40' 01" N	2414	1998
Antone Lower	ATL 1-3	116° 54' 20" W	38° 40' 05" N	2402	1998
Barley	BA 1-4	116° 41' 17" W	38° 37' 44" N	2270	1998
Big Creek Lower	BCL 1-3	117° 07' 45" W	39° 20' 15" N	2110	1995
Big Creek Mid.	BCM 1-3	117° 04' 25" W	39° 20' 11" N	2119	1998
Cottonwood	CW 1-3	117° 17' 10" W	39° 09' 02" N	2084	1995
Kingston	KG 1-3	117° 09' 52" W	39° 15' 04" N	2278	1998
Marysville *	MV 1-3	117° 20' 45" W	39° 02' 37" N	2055	1995
San Juan Upper	SJU 1-3	117° 17' 01" W	39° 08' 11" N	2133	1995
San Juan Lower	SJL 1-3	117° 17' 09" W	39° 08' 21" N	2124	1995
Stoneberger Upper	SBU 1-3	116° 48' 25" W	38° 06' 01" N	2450	1998
Stoneberger Lower	SBL 1-3	116° 48' 07" W	38° 06' 02" N	2350	1998
Washington Upper	WCU 1-3	117° 14' 09" W	39° 09' 16" N	2319	1995
Washington Lower	WCL 1-3	117° 14' 20" W	39° 09' 13" N	2300	1998

* channel change data 1995 – 1998 missing.

Table 3. The site name, code and transect numbers, location, elevation and geomorphic position for the 1999 study sites (component 2).

	Site name	Site code/ transect	Latitude	Longitude	Elevation meters	Geomorphic position
Fans without Meadows	Antone	ATF 1	116° 54' 42" W	38° 40' 07" N	2427	Above
	Antone	ATF 2-4	116° 54' 38' W	38° 40' 04" N	2420	Fan
	Antone	ATF 5	116° 54' 30" W	38° 40' 01" N	2414	Below
	Barley	BAF 1	116° 41' 10" W	38° 37' 44" N	2270	Above
	Barley	BAF 2-5	116° 41' 17" W	38° 37' 44" N	2269	Fan
	Big Creek	BCF 1	117° 04' 25" W	39° 20' 11" N	2119	Above
	Big Creek	BCF 2-4	117° 07' 45" W	39° 20' 15" N	2110	Fan
	Big Creek	BCF 5	117° 08' 00" W	39° 20' 25" N	2080	Below
	Stoneberger	SBF 1	116° 48' 25" W	38° 06' 01" N	2450	Above
	Stoneberger	SBF 2-5	116° 48' 10" W	38° 06' 02" N	2400	Fan
	Washington	WCF 1	117° 13' 45" W	39° 09' 20" N	2365	Above
	Washington	WCF 2-4	117° 14' 00" W	39° 09' 18" N	2319	Fan
	Washington	WCF 5	117° 14' 09" W	39° 09' 16" N	2393	Below
Fans with Meadows	Big Creek	BCMdw 1-4	117° 07' 18" W	39° 19' 28" N	2150	Above
	Big Creek	BCMdw 5-7	117° 07' 16" W	39° 19' 38" N	2146	Fan
	Big Creek	BCMdw 8	117° 07' 10" W	39° 19' 45" N	2141	Below
	Birch	BHMdw 1-4	117° 05' 10" W	39° 22' 30" N	2425	Above
	Birch	BHMdw 5-7	117° 04' 55" W	39° 22' 45" N	2415	Fan
	Cottonwood	CWMdw 1-5	117° 16' 20" W	39° 08' 25" N	2144	Above
	Cottonwood	CWMdw 6-8	117° 16' 25" W	39° 08' 20" N	2140	Fan
	Cottonwood	CWMdw 9	117° 16' 30" W	39° 08' 15" N	2134	Below
	Kingston upper	KMU 1-4	117° 09' 28" W	39° 16' 23" N	2314	Above
	Kingston upper	KMU 5-7	117° 09' 30" W	39° 16' 15" N	2315	Fan
	Kingston upper	KMU 8	117° 09' 35" W	39° 16' 10" N	2317	Below
	Kingston lower	KML 1-3	117° 09' 54" W	39° 15' 20" N	2280	Above
	Kingston lower	KML 4-6	117° 09' 52" W	39° 15' 10" N	2278	Fan

Table 4. Multiple linear regression results for the 1998 geomorphic data. Measures of channel incision (1995-1998) and channel morphology as dependent variables vs. channel and bank geomorphic characteristics as predictor variables.

	Area change highflow(%) (n=14)		Depth change highflow(%)		Depth at measured peak(cm)		Depth highflow(cm) (n=40)		Width/Depth at measured peak (n=37)	
Variable	% contr.[1]	+/-[2]	% contr.[1]	+/-[2]	% contr.[1]	+/-[2]	% contr.[1]	+/-[2]	% contr.[1]	+/-[2]
Bank d84 (n=41)	43***	-			8	-			25***	+
Channel d84 (n=38)					35***	-	24	-	29***	+
Channel d50/d84 (n=38)					36***	+	28*	+	46***	-
Bank d50/bank d84 (n=41)			34**	+						
% silt and clay in banks (n=41)					12*	+				
Width/depth measured peak(n=37)	42***	-								
Height 1st Terrace (n=43)	15*	+	44***	+						
Depth bankfull/ depth valley floor (n=43)			22**	+						
Depth valley floor (n=41)					9*	+	48**	+		
TOTAL R^2	0.81***		0.75***		0.57***		0.37***		0.49***	

Only significant variables after stepwise backward elimination are presented.

*P<.1 **P<.05 ***P<.01

[1] Percentage contribution to R^2

[2] Regression slope positive/negative direction.

Table 5. Multiple linear regression results for the 1998 geomorphic and vegetation cover data. Measures of channel incision (1995-1998) and channel morphology as dependent variables.

	Depth change highflow(%) (n=14)		Depth at measured peak(cm)		Depth highflow(cm) (n=40)		Width/Depth at measured peak (n=37)	
Variable	% contr.[1]	+/-[2]	% contr.[1]	+/-[2]	% contr.[1]	+/-[2]	% contr.[1]	+/-[2]
Bank d84 (n=41)			37***	-			22**	+
Bank d50/bank d84 (n=41)							7	-
% silt and clay in banks (n=41)								
Channel d84 (n=38)							19**	+
Channel d50d84 (n=38)							25***	-
Width/depth measured peak (n=37)	9**	-						
Height 1st Terrace (n=43)	29**	+						
Depth valley floor (n=41)								
Density bunch willows 0m (n=41)					16**	-		
Bunch willow %max. 0m (n=43)					6	-		
Density Salix exigua 2m (n=41)	49***	+						
Bunch willow %min. 2m (n=43)			4*	+				
Bunch willow mxht. 2m (n=43)			21***	+			16**	-
Basal cover litter at 0m (n=43)			17***	+				
Basal cover veg. at 0m (n=43)					17**	-		
Basal cover rock at 1m (n=43)					46***	-	11*	+
Aerial cover veg. at 0m (n=43)			21***	-				
Aerial cover veg. at 2m (n=41)	13**	+						
Aerial cover litter at 0m (n=41)					15**	+		
TOTAL R^2	0.92***		0.73***		0.52***		0.61***	

Only significant variables after stepwise backward elimination are presented.

*P<.1 **P<.05 ***P<.01

[1] Percentage contribution to R^2

[2] Regression slope positive/negative direction.

Table 6. Key species associated with vegetation groups at 0, 1 and 2 meters. Groups are based upon divisions in the TWINSPAN classification two-way ordered tables. The group heading describes the drainage best represented by that group, the sites codes under the heading are other sites included in the group. In most cases a group involved cross sections from several sites. The outliers* grouped more distinctly on drainage.

Group 0 m	Species	Group 1 m	Species	Group 2 m	Species
Barley*	Carex lanuginosa	Barley*	Carex lanuginosa	Barley*	Carex lanuginosa
	Juncus longystyllus		Conyza candensis	(ATL1)	Leymus triticoides
	Conyza canadensis		Agrostis scabra		Artemisia ludoviciana
	Eleocharis macrostachya				
	Potentilla glandulosa			KG,WCU,	Poa pratensis
				WCL1,2,	Carex spp.
Kingston*	Phalaris arundinaceae	Kingston	Phalaris arundinacea	ATU2)	
	Carex nebrascensis	(SBU2)	Carex nebrascensis		
	Equisitum arvense		Achillea millefolia	Big creek	Meliotus officinale
			Salix exigua	(ATU1,3)	Poa pratensis
Big creek	Achillea millefolium				
(SJL2, CW2)	Poa pratensis	Big Creek*	Agropyron intermedium	SJL, CW, MV	Achillea millifolia
	Agrostis stolonifera	(SJU1 SJL2)	Melilotus officinale		Salix lutea
	Equisitum hymenale		Poa pratensis		Agrostis stolonifera
	Cicuta douglasii				Poa pratensis
	Senecio hydrophyllus				
		Antone	Aster spathula		
Antone	Deschampsia caespitosa	(SBL3 SBU3	Artemesia tridentada	Stoneberger*	Lupinus argenteus
(AT)	Poa pratensis	CW2,3)	Poa pratensis	Lower	Chrysnothamnus
	Salix boothii				nauseosus
	Aster spathula	Marysville	Equisitum arvense	SBU,SJU, AT	No vegetation
			Mentha arvense	CW	
			Juncus nevadense		
Marysville	Mentha arvense		Juncus balticus		
(MV)	Carex lanuginosa		Viola spp.		
	Equisitum arvense		Agrostis stolonifera		
	Trifolium wormskijoldii				
Washington	Achillea millefolium	Washington	Cicutia douglasii		
(SJU1,2 SJL3	Cicuta douglasii	(SBU1)	Equisitum arvense		
CW1,2 SBU	Senecio hydrophyllus		Poa pratensis		
SBL2)	Poa pratensis		Agrostis stolonigera		
	Equisitum arvense				
	Agrostis stolonifera	San Juan	Poa pratensis		
		(SBL1,2,CW1	Salix lutea		
Mixed	Mimmulus guttatus	WCL2)	Zigadeneus paniculata		
(BCM2,	Stellaria longipes				
WCU2	Salix lutea				
SJU3, SJU1)	Viola spp.				

* Outlier groups according to TWINSPAN and RA

Table 7. Multiple linear regression results for the 1998, vegetation composition data vs. geomorphic and willow data. Reciprical averaging (RA) axes 1 and 2 from nested rooted frequency data (at 0,1 and 2 meters from stream) as dependent variables.

	0 meter				1 meter				2 meter			
	Axis 1 (n=39)		Axis 2 (n=38)		Axis (n=39)		Axis 2 (n=41)		Axis 1 (n=32)		Axis 2 (n=30)	
Variable	% contr.^{1}	+/-^{2}	% contr.^{1}	+/-^{2}	% contr.^{1}	+/-^{2}	% contr.^{1}	+/-^{2}	% contr.^{1}	+/-^{2}	% contr.^{1}	+/-^{2}
Bank d50 (n=41)									NS		NS	
Bank d65 (n=41)					23***	-	6	-			NS	
Bank d84 (n=41)					NS		14**	-			NS	
Critical q d50/q peak (n=37)	42**	+	10*	+								
Critical q bank d50/q peak (n=37)	22*	+	20*	-								
Bank d50/bank d84 (n=41)			36***	+	NS		NS					
% silt and clay in banks (n=41)	NS		NS		NS		NS		26***	+	NS	
Critical q for bank d84 (n=41)									10**	-	NS	
Discharge per unit width (q)(n=37)	NS		NS		NS		57***	-	NS		NS	
Depth at peak flow (n=37)					38***	-	7	-				
Width/depth at peak flow (n=37)					NS		NS					
Width bankfull (n=40)					NS		16**	+	7***	+	NS	
Area bankfull (n=40)									15***	+	30***	+
Area high flow (estimated) (n=40)									NS		NS	
Area at peak flow (n=37)	NS		NS									
Depth valley floor (n=41)	35**	-	34***	-					7**	+	45***	-
Density bunch willows 0m (n=41)	NS		NS									
Density Salix exigua 0m (n=41)	NS		NS									
Density Salix exigua 1m (n=41)					39***	+	NS					
Density bunch willows 1m (n=41)					NS		NS					
Density bunch willows 2m (n=41)									25***	+	NS	
Density Salix exigua 2m (n=41)									NS		25**	+
Eigen values for RA axes	0.52		0.4		0.69		0.59		0.85		0.69	
TOTAL R^2	0.36***		0.34*		0.48***		0.57***		0.84***		0.31**	

*P<.1, **P<.05, ***P<.01 NS= not significant

[1] % contribution to R^2

[2] slope positive/negative

Table 8a-c: Standardized discriminant canonical coefficients for environmental data used in re-classification of 1998 TWINSPAN nested rooted frequency groups; (a) 0 meters from stream, (b) 1meter from stream and (c) 2 meters from stream.

a

	Standardized canonical coefficients			
Variable	Factor 1	Factor 2	Factor 3	Factor 4
Discharge unit width	-0.032	0.79	1.06	-----
% silt-clay banks	1.65	1.83	-0.09	-----
Bank d84 (b84)	-0.94	1.45	0.2	-----
Depth valley floor	1.47	-0.29	0.52	-----
Eigen values	7.36	2.47	1.29	0.09
Variation explained	65.6%	22.1%	11.5%	1.8%

b

	Standardized canonical coefficients		
Variable	Factor 1	Factor 2	Factor 3
Width bankfull	1.05	-0.31	1.1
Channel d84	0.4	2.04	-0.29
Bank d84 (b84)	-1.34	-1.26	1.25
Eigen values	3.17	1.8	0.55
Variation explained	57%	33%	10%

c

	Standardized canonical coefficients			
Variable	Factor 1	Factor 2	Factor 3	Factor 4
Area bankfull	-1.25	1.38	0.37	-----
Critical shear d84/ shear at peak flow	6.87	0.77	0.97	-----
Bank d50 (b50)	1.55	0.85	-2.03	-----
Bank d84 (b84)	0.26	-0.43	2.51	-----
Critical shear b84/ shear at peak flow	-7.8	0.69	-0.6	-----
Critical discharge b84	3.04	-1.56	0.44	-----
Eigen values	10.3	2.04	1.7	0.77
Variation explained	69%	14%	11%	5%

Table 9. Key species, in order of importance, associated with vegetation groups at 0 and 1 meter for fans with meadows, 1999 data. Groups are based upon divisions in the TWINSPAN classification two-way ordered tables. The group column lists all cross sections in that group. Symbols describe fan position: * fan, + above fan, # below fan. Species chosen for initial correlation matrix against fan position denoted by °.

Group 0 m	Species	Group 1 m	Species
KMU 2-4^{+}& 5*	Carex nebrascensis °	KMU 1-4^{+} & 5*	Carex nebrascensis °
KML 1^{+}			Poa pratensis
			Moss °
KML 5&6*	Poa pratensis		Juncus balticus
CWM 1&5^{+}	Salix exigua		
BHM7*		KML 2&4^{+}, 5&6*	Poa pratensis
		CWM 7* &9$^{\#}$	Juncus balticus
BHM 2,3,4^{+}& 6*	Poa pratensis	BHM 2^{+}, 5&6*	Aster spathula °
CWM 2,3,4^{+},6* &7*	Aster spathula °		Taraxicum officinale
KMU 1^{+}& 7*	Juncus ensifolius		Salix exigua
KML 2^{+}	Carex nebrascensis °	KMU 6&7*	
	Taraxicum officinale	BC 1-4^{+},5-7*	Poa pratensis
KMU 6* & 8$^{\#}$		& 8$^{\#}$	Agropyron intermedium°
BC 1-4^{+},5-7*	Poa pratensis		Equisitum hymenale
& 8$^{\#}$	Agrostis stolonifera °		Melilotus officinale
CWM 9$^{\#}$ & 8*	Cicuata douglasii °		Agrostis stolonifera °
	Equisitum hymenale	KMU 8$^{\#}$	
BHM 1^{+}, 5*		CWM 5^{+}	Poa pratensis
	Rorripa nasturtium-		Bromus tectorum
	aquatica		Iva axillaris
	Artemesia tridentada		Leymus triticoides °
	Rumex crispus	BHM 1^{+}	
			Mimmulus guttatus
			Epilobium ciliatum
			Rumex crispus
			Poa pratensis
			Sagina saginoides

Table 10. Key species, in order of importance, associated with vegetation groups at 0 and 1 meter for fans without meadows, 1999 data. Groups are based upon divisions in the TWINSPAN classification two-way ordered tables. The group column lists all cross sections in that group. Symbols describe fan position: * fan, + above fan, # below fan.
Species chosen for initial correlation matrix against fan position denoted by °.

Group 0 m	Species	Group 1 m	Species
BAF 1^{-} & 3^{*}	Veronica peregrina	BAF 1^{+}, 2, $4\&5^{*}$	Salix exigua
	Carex lanuginosa °		Salix lutea
	Epilobium ciliatum		Epilobium ciliatum
BAF 2, 4 & 5^{*}	Carex lanuginosa °	BCF 2, 4^{*} & $5^{\#}$	Poa pratensis
SBF 2 & 4^{*}	Moss °	SBF $5^{\#}$	Salix exigua
	Cicuta douglasii °		Taraxicum officinale
ANF 1^{-},2,3,4^{*} & $5^{\#}$	Deschampsia caespitosa	WCF 2-4^{*}, & $5^{\#}$	Poa pratensis
	Moss °		
SBF 3^{*}	Poa pratensis	SBF 1^{+}	Cicuta douglasii °
	Cicuta douglasii °		Achillea millefolium
			Taraxicum officinale
BCF 1^{+},2,3,4^{*}& $5^{\#}$	Cicuta douglasii °		Agrostis stolonifera
	Poa pratensis		Salix exigua
	Agrostis stolonifera		Equisitum arvense
	Melilotus officinale		
	Agropyron spp. °		
		ATF 1^{+}, 2-4^{*} & $5^{\#}$	Salix boothii
WCF 1^{+},2,3,4^{*}& $5^{\#}$	Cicuta douglasii °		Poa pratensis
SBF 1^{+} & $5^{\#}$	Achillea millefolium		Aster spathula °
	Equisitum avense		Deschampsia caespetosa
			Cicuta douglasii °
		WCF 1^{+}	No vegetation
		BCF 1^{+}	
		SBF 2^{*}	

Table 11 a-c. Discriminant function analysis classification matrix of fan position groups with geomorphic and vegetation characteristics used for reclassification from 1999 data for: (a) fans with meadows (b) fans without meadows (c) all fans

a

Original fan position	Predicted category membership		
	Above	Fan	Below
Above (n=19)*	19 100%	0 0%	0 0%
Fan (n=15)	1 6.67%	13 86.67%	1 6.67%
Below (n= 3)	0 0%	2 66.67%	1 33.33%
Total transects	20	15	12

error rate 10.8% * minus CWM 5

b

Original fan position	Predicted category membership		
	Above	Fan	Below
Above (n=6)	4 66.67%	1 16.67%	1 16.67%
Fan (n= 15)	0 0%	15 100%	0 0%
Below (n=4)	2 50%	0 0%	2 50%
Total transects	6	16	3

error rate 16%

c

Original fan position	Predicted category membership		
	Above	Fan	Below
Above (n=26)	19 73.08%	5 19.23%	2 7.69%
Fan (n= 30)	7 23.33%	23 76.67%	0 0%
Below (n=7)	3 42.86%	2 28.57%	2 28.57%
Total transects	29	22	4

error rate 30%

Table 12a-c. Standardized discriminant canonical coefficients fan position were the original groups. Geomorphic and vegetation data were used to reclassify cross sections: (a) fans with meadows (b) fans without meadows (c) all fans.

a

		Standardized coefficients	
Variable	Factor 1	Factor 2	Factor 3
Ht. 1st Terrace	-0.59	0.44	0.60
Ratio entrenchment	1.06	-0.27	0.39
Bank d50/channel d50	0.89	0.07	0.14
Channel d50/d84	-0.42	0.47	0.32
Bunch willow % max. 1m	0.59	0.62	-0.34
Salix exigua % max. 0 m	1.45	1.0	0.54
Aerial cover veg. 1m	-1.1	0.67	-0.57
Carex nebrascensis 0m	0.78	0.36	0.07
Aerial cover veg. 0 m	0.94	0.84	0.32
Bunch willow % max. 0m	-0.31	0.73	0.05
Wetland species 1m	-1.06	-0.45	0.96
Eigen values	6.35	1.01	------
Variation explained %	86.2%	13.8%	

b

		Standardized coefficients	
Variable	Factor 1	Factor 2	Factor 3
Slope (%)	-4.25	0.21	0.23
Ratio entrenchment	-2.25	-1.26	-0.60
% silt-clay stream banks	6.82	2.11	1.61
Channel d50/d84	9.08	0.70	0.96
Critical shear d50/shear	-1.76	-0.25	-1.30
Ratio depth valley floor	1.38	1.96	1.18
Channel d84 (mm)	1.32	0.09	0.08
Bank d84 (mm)	5.55	0.32	0.51
Salix exigua % max. 1m	2.12	-0.56	-0.72
Salix exigua % max. 0 m	-1.43	0.30	0.58
Carex nebrascensis 0m	5.22	-0.57	0.07
Basal bareground 0m	2.17	-0.39	-0.08
Eigen values	27.56	1.17	------
Variation explained %	95.9%	4.1%	

c

		Standardized coefficients	
Variable	Factor 1	Factor 2	Factor 3
Ratio entrenchment	-0.49	0.45	0.77
Channel d50/d84	0.61	0.23	0.65
Aerial cover veg. 1m	0.90	0.51	-0.01
Slope (%)	-0.32	0.84	-0.44
Eigen values	.734	.088	------
Variation explained %	89.3%	10.7%	

Figure 1: Map of site locations

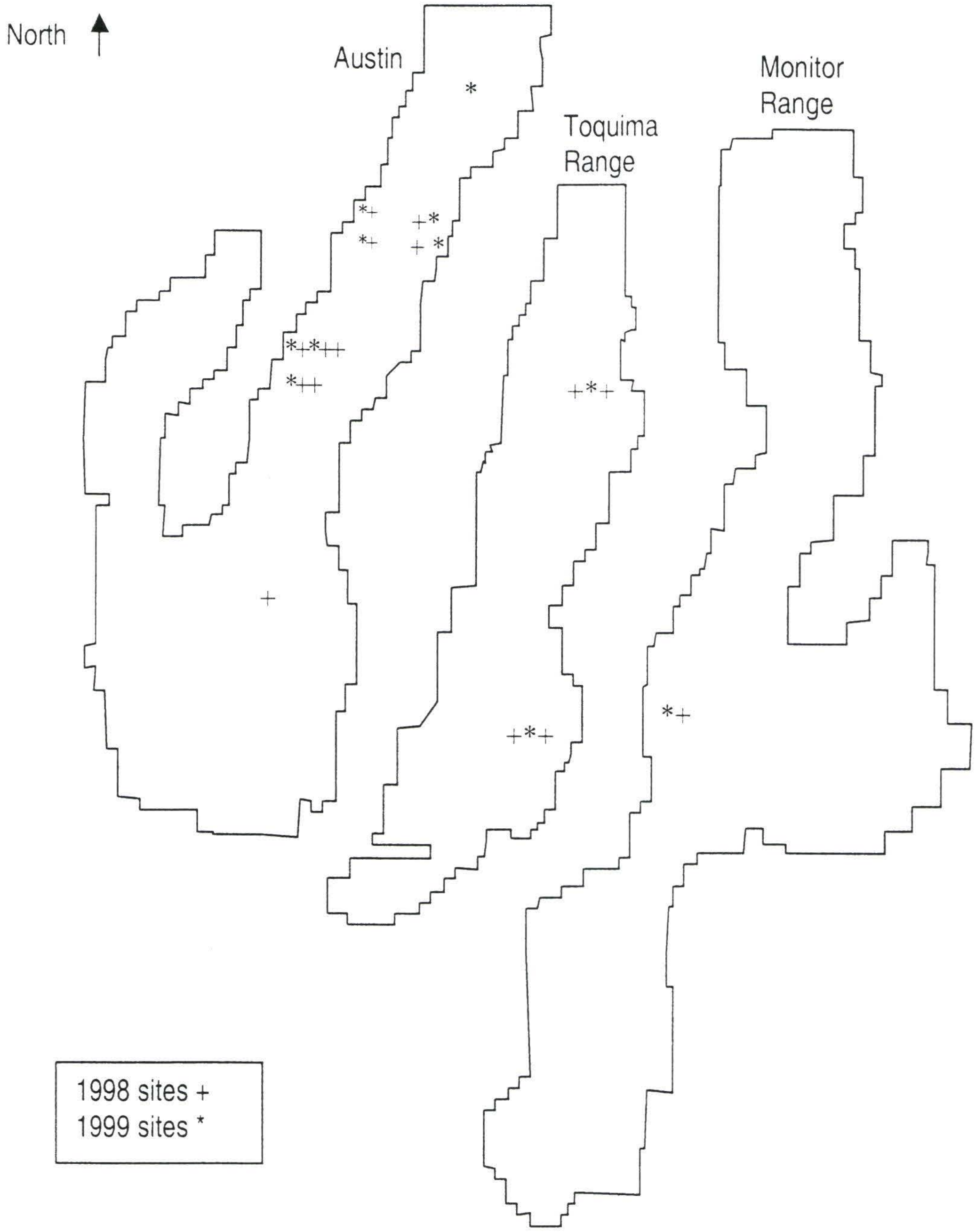

North
Austin
Toquima Range
Monitor Range
1998 sites +
1999 sites *

Figure 2. Sample cross section showing bankfull, first terrace, second terrace and valley floor.

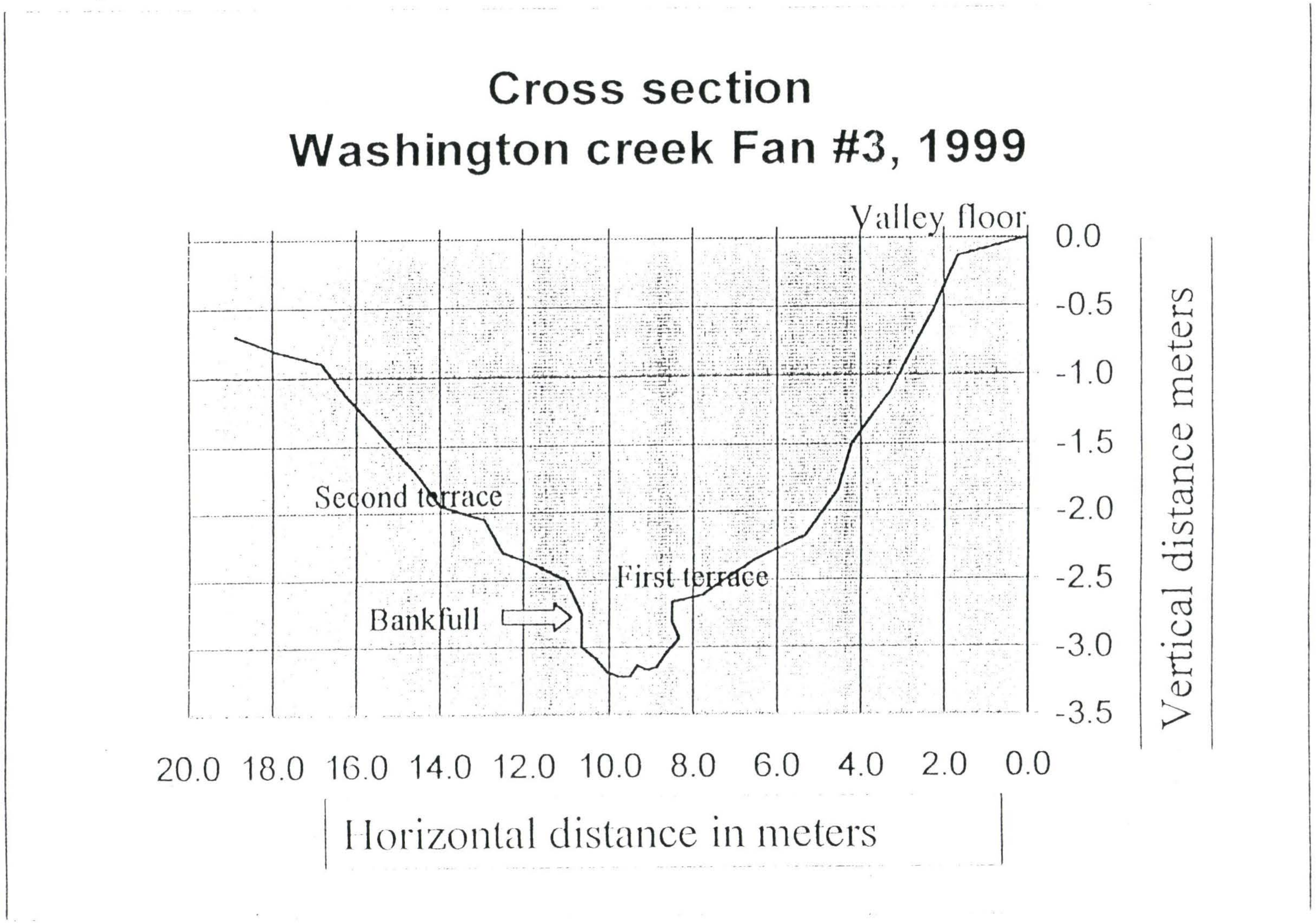


Figure 2. Sample cross section showing bankfull, first terrace, second terrace and valley floor.

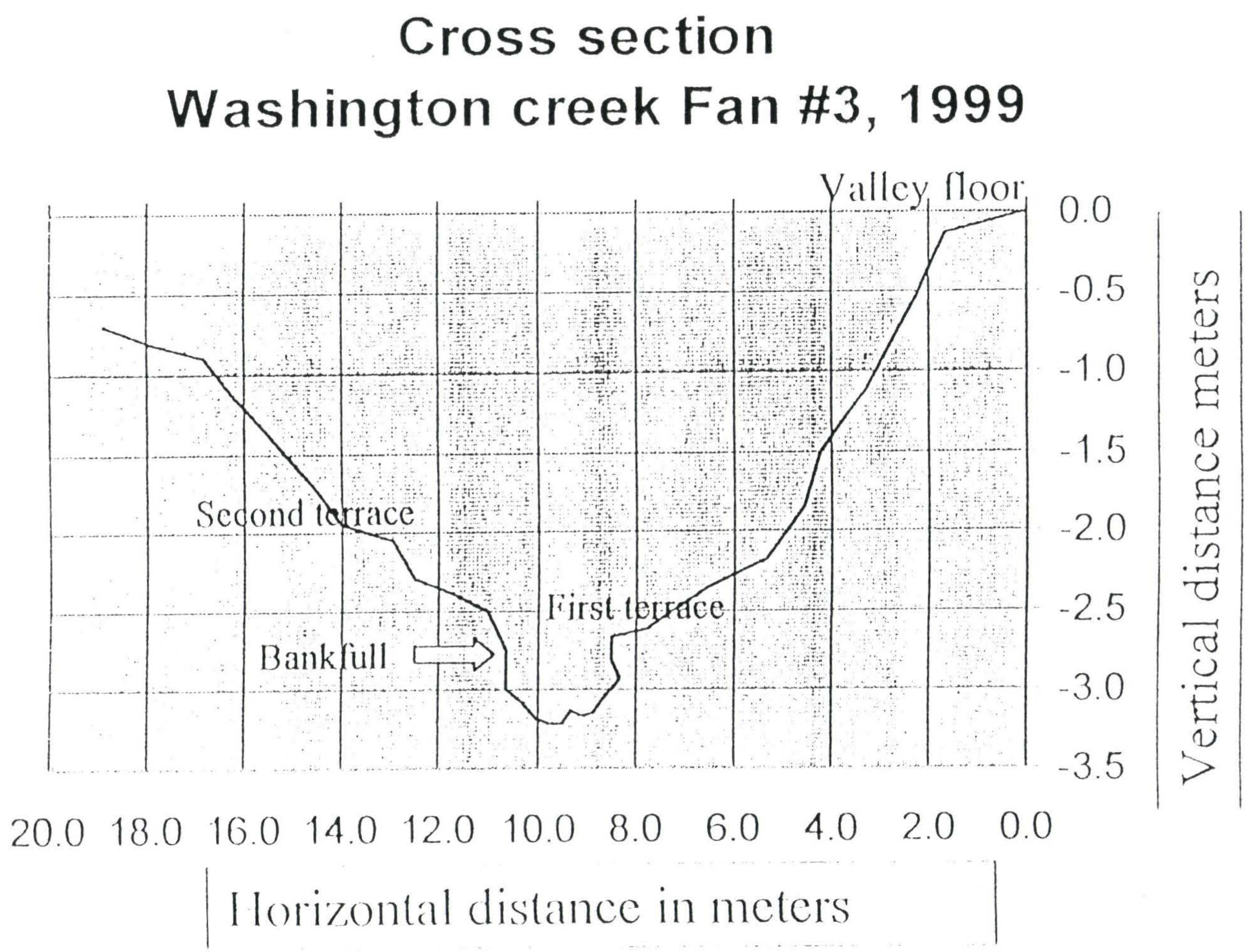


Figure 3. Kingston meadow upper, 1999 channel cross sections:
Measured vertically from valley floor to channel bottom. • = bankfull level

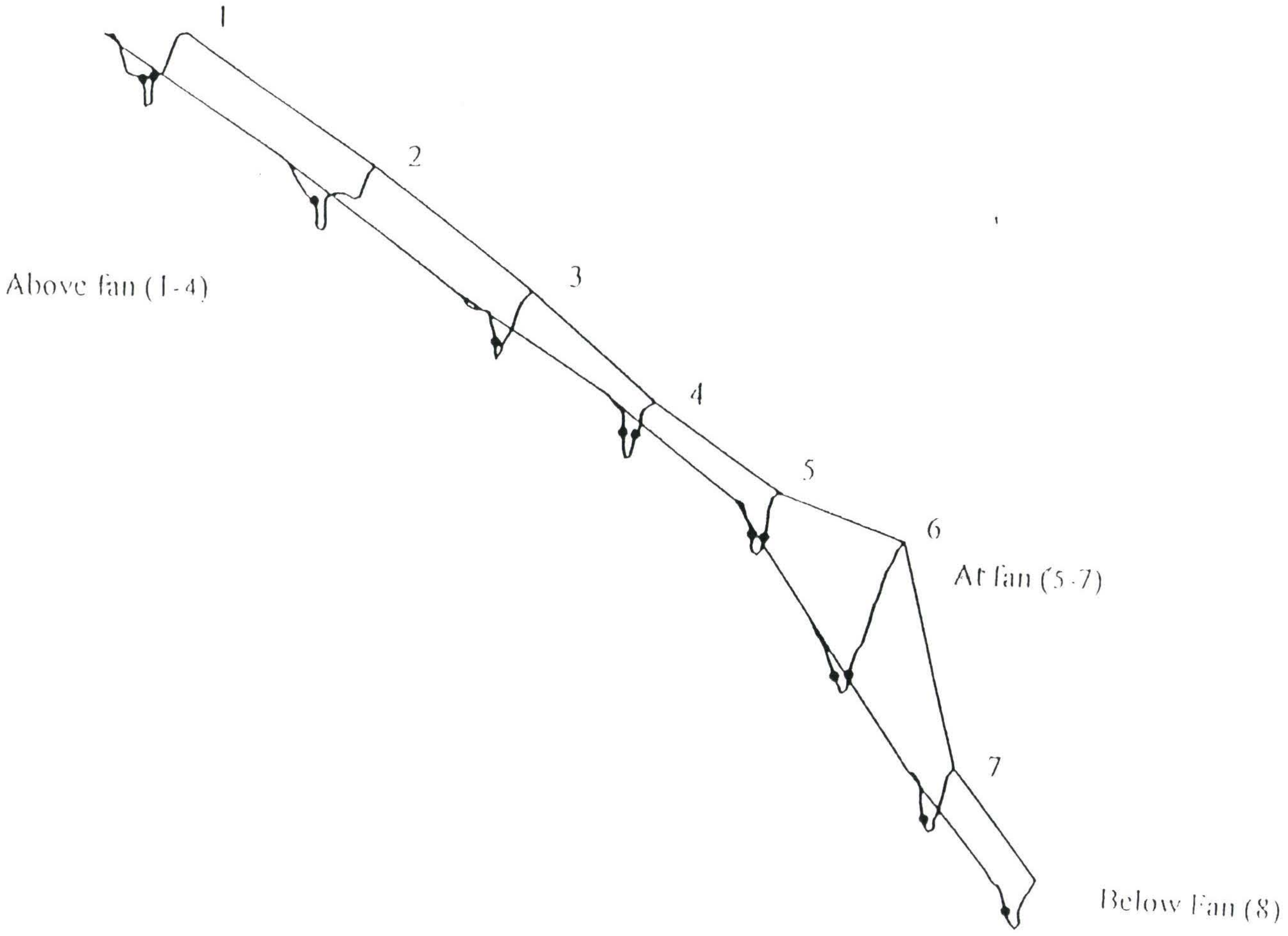

1
2
3
4
5
6
7
Above fan (1-4)
At fan (5-7)
Below Fan (8)

Figure 4. The relationships between channel area change between 1995 and 1998 (%) vs. (a) the change in channel depth between 1995 and 1998 (%), and (b) the width/depth ratio of the flowing channel at measured peak 1998.

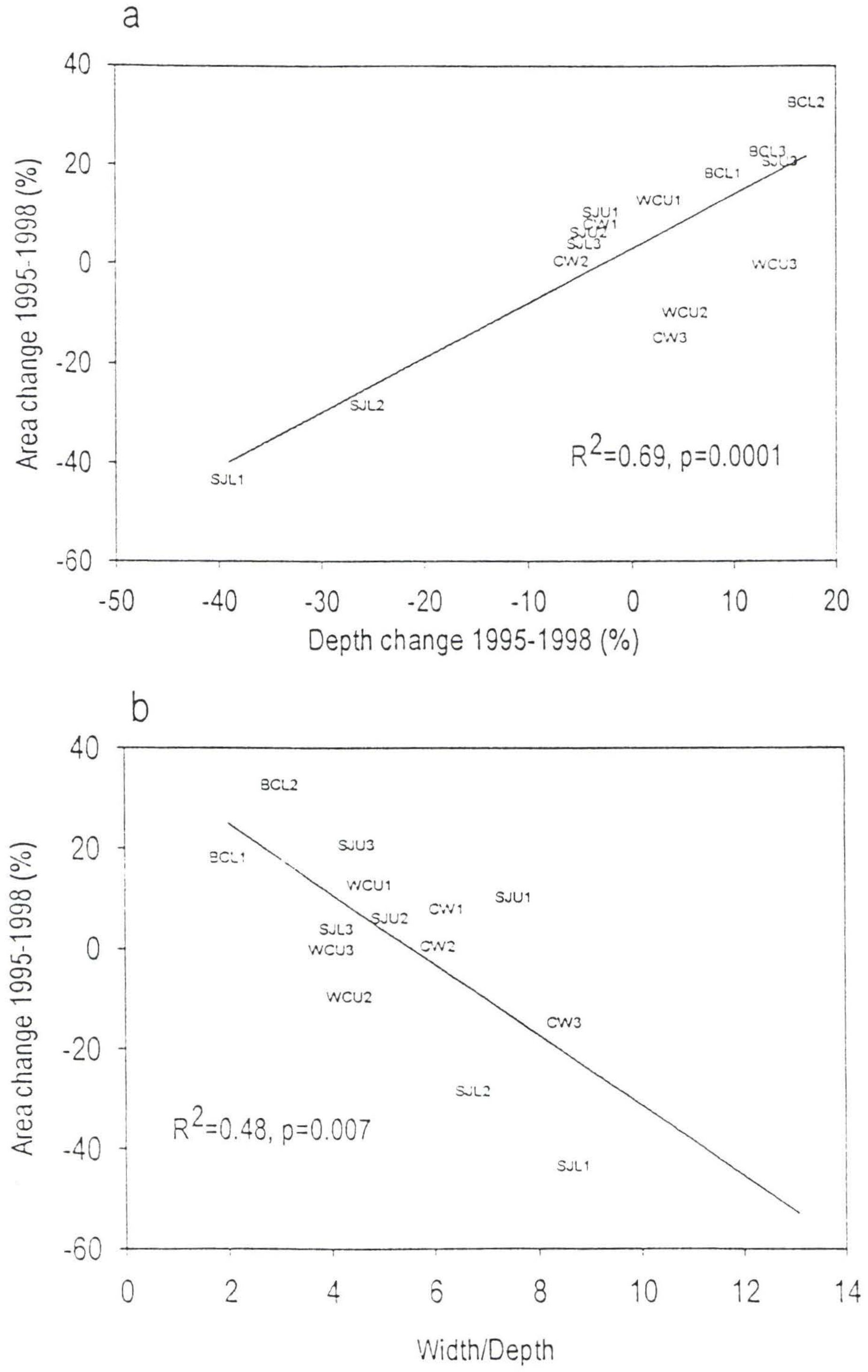


Figure 5. The relationship between the ratio of the channel d50/d84 particle sizes (mm) vs. (a) the depth change between 1995 and 1998 (%), (b) the width/depth ratio of the flowing channel at measured peak in 1998, (c) the depth of flow at measured peak in 1998 (cm).

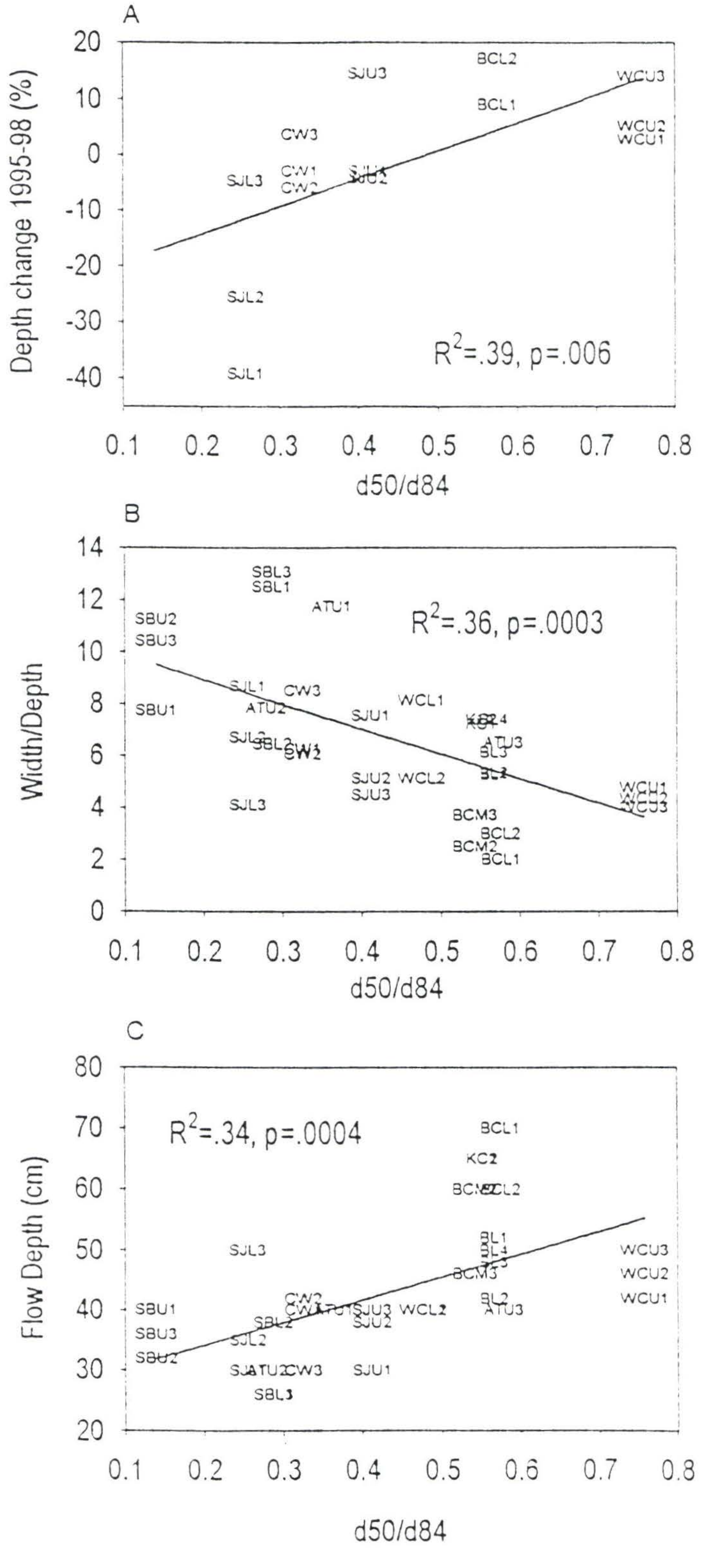


Figure 6. The relationship between the depth of flow at measured peak 1998 vs. the channel d84 particle size (mm).

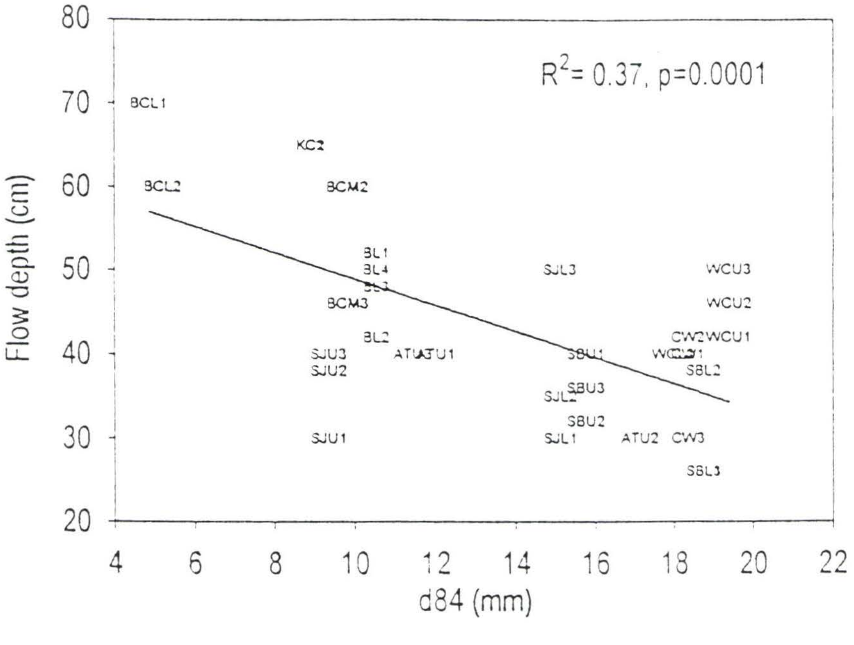


Figure 7. The relationship between change in channel depth between 1995 and 1998 (%) vs. ratio of channel at bankfull/depth from valley floor to channel bottom in 1998.

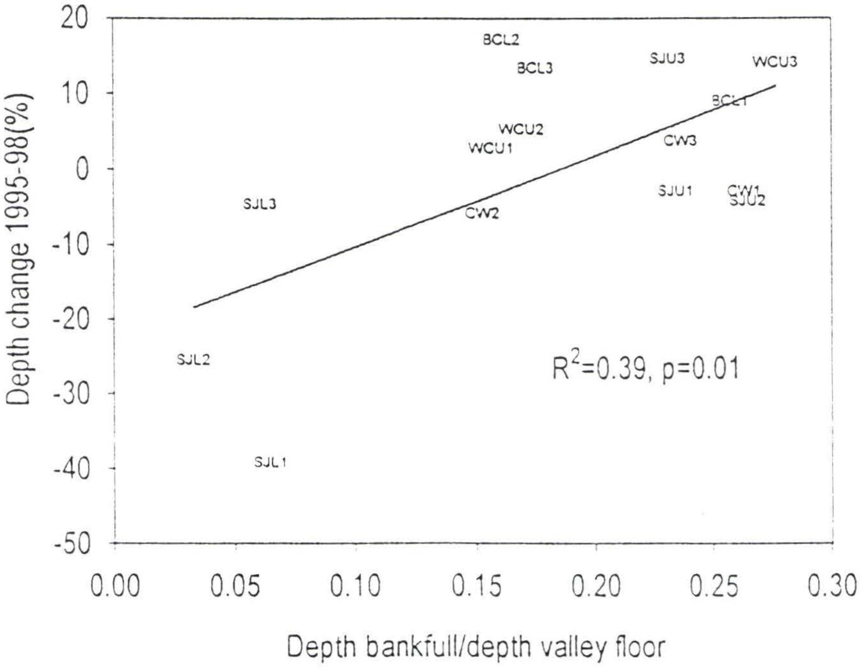


Figure 8. Discriminant function analysis scatter plot for the 1998, 0 meter data showing separation of the twinspan groups based on geomorphic variables. Vectors show contribution of each variable to factors 1 and 2. Outlier groups Kingston (KG) and Barley (BL) show most distinct separation.

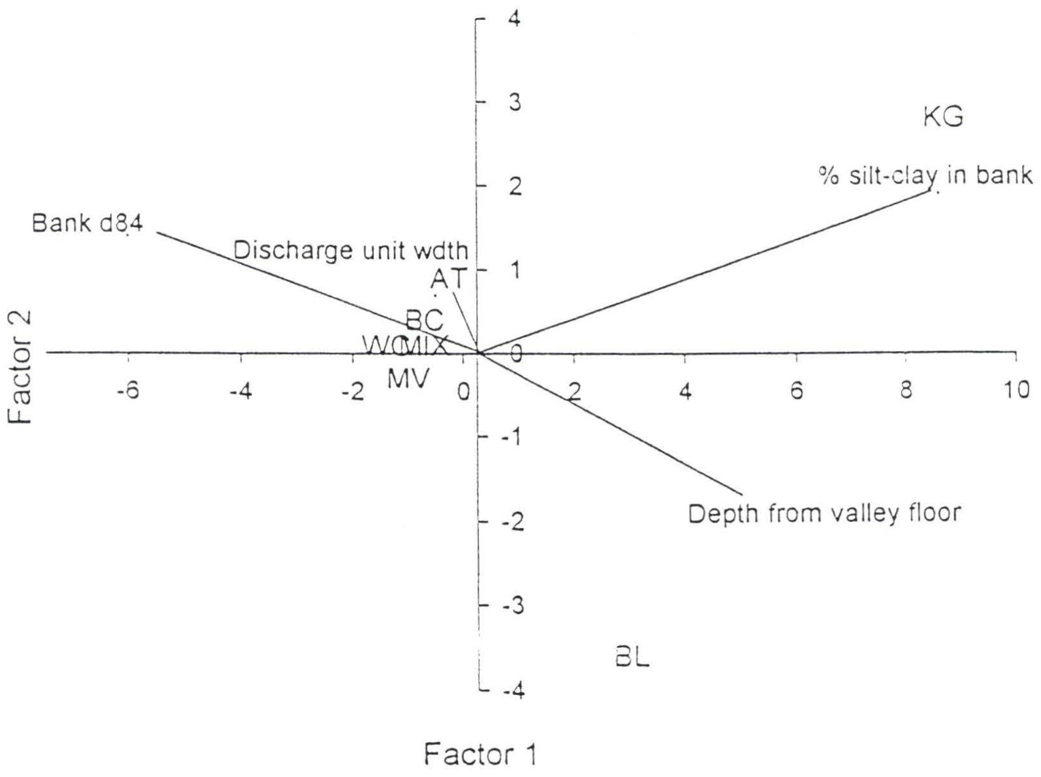


Figure 9. Discriminant function analysis scatter plot for the 1998,1 meter data showing separation of the twinspan groups based on geomorphic variables. Vectors show contribution of each variable to factors 1 and 2. Outlier groups Barley (BL) and Big Creek (BC-SJU1-SJL1) exhibit most distinct separation.

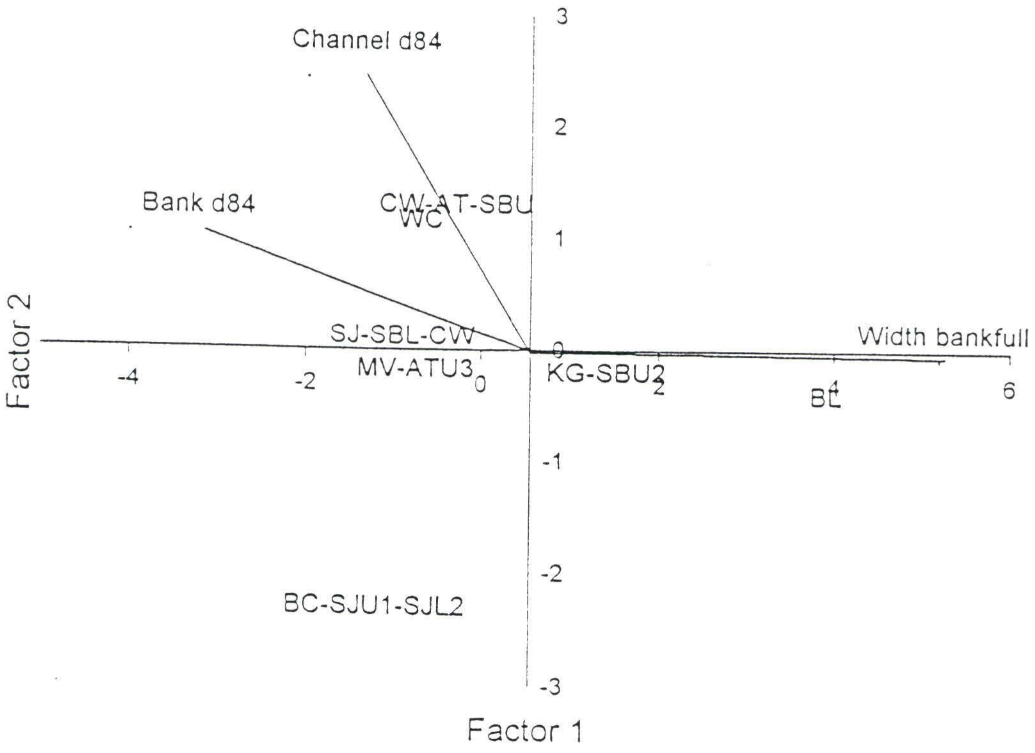


Figure 10. Discriminant function analysis scatter plot for the 1998, 2 meter data showing separation of twinspan groups based on geomorphic variables. Vectors show contribution od each variable to factors 1 and 2. Outlier groups Stoneberger Lower (SBL) and Barley (BL-ATL1) show most distinct separation.

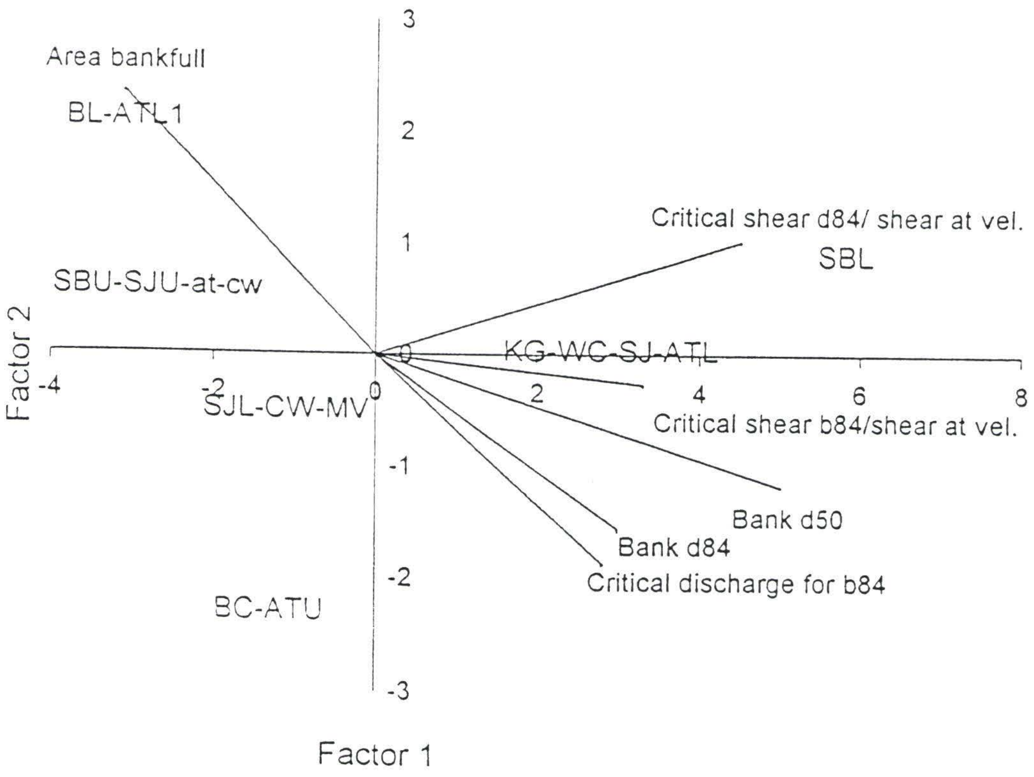
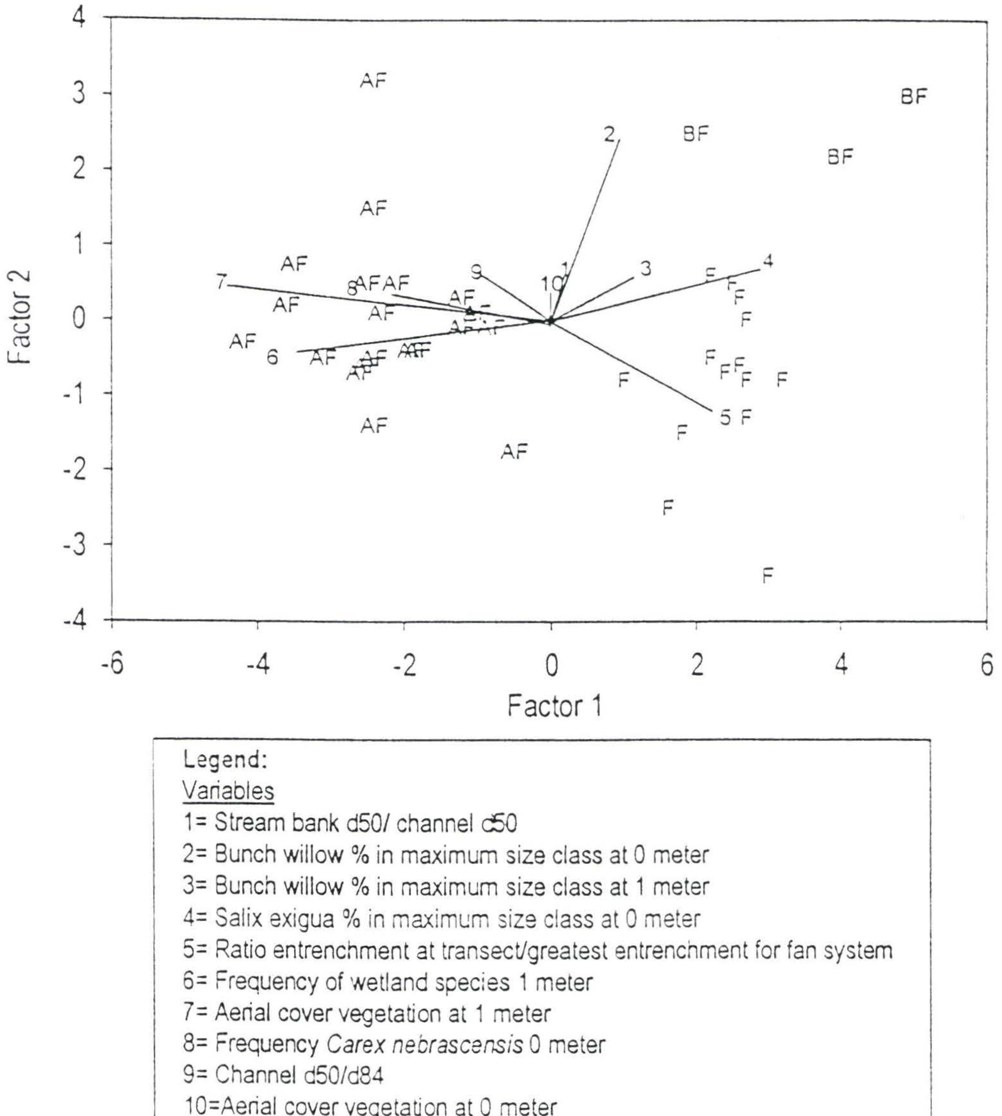


Figure 11. Discriminant function analysis scatter plot for 1999 fans with meadows. Distribution of fan positions shown as points. Environmental characteristics used as re-grouping variables. Vectors show how each variable contributes to discriminant factors 1 and 2.



Legend:

Variables

1= Stream bank d50/ channel d50
2= Bunch willow % in maximum size class at 0 meter
3= Bunch willow % in maximum size class at 1 meter
4= Salix exigua % in maximum size class at 0 meter
5= Ratio entrenchment at transect/greatest entrenchment for fan system
6= Frequency of wetland species 1 meter
7= Aerial cover vegetation at 1 meter
8= Frequency *Carex nebrascensis* 0 meter
9= Channel d50/d84
10=Aerial cover vegetation at 0 meter

Fan Positions

AF= above fan, F= fan, BF= below fan

Figure 12. Discriminant function analysis scatter plot for 1999 fans without meadows. Distribution of fan positions shown as points. Environmental characteristics used as re-grouping variables. Vectors show how each variable contributes to discriminant factors 1 and 2.

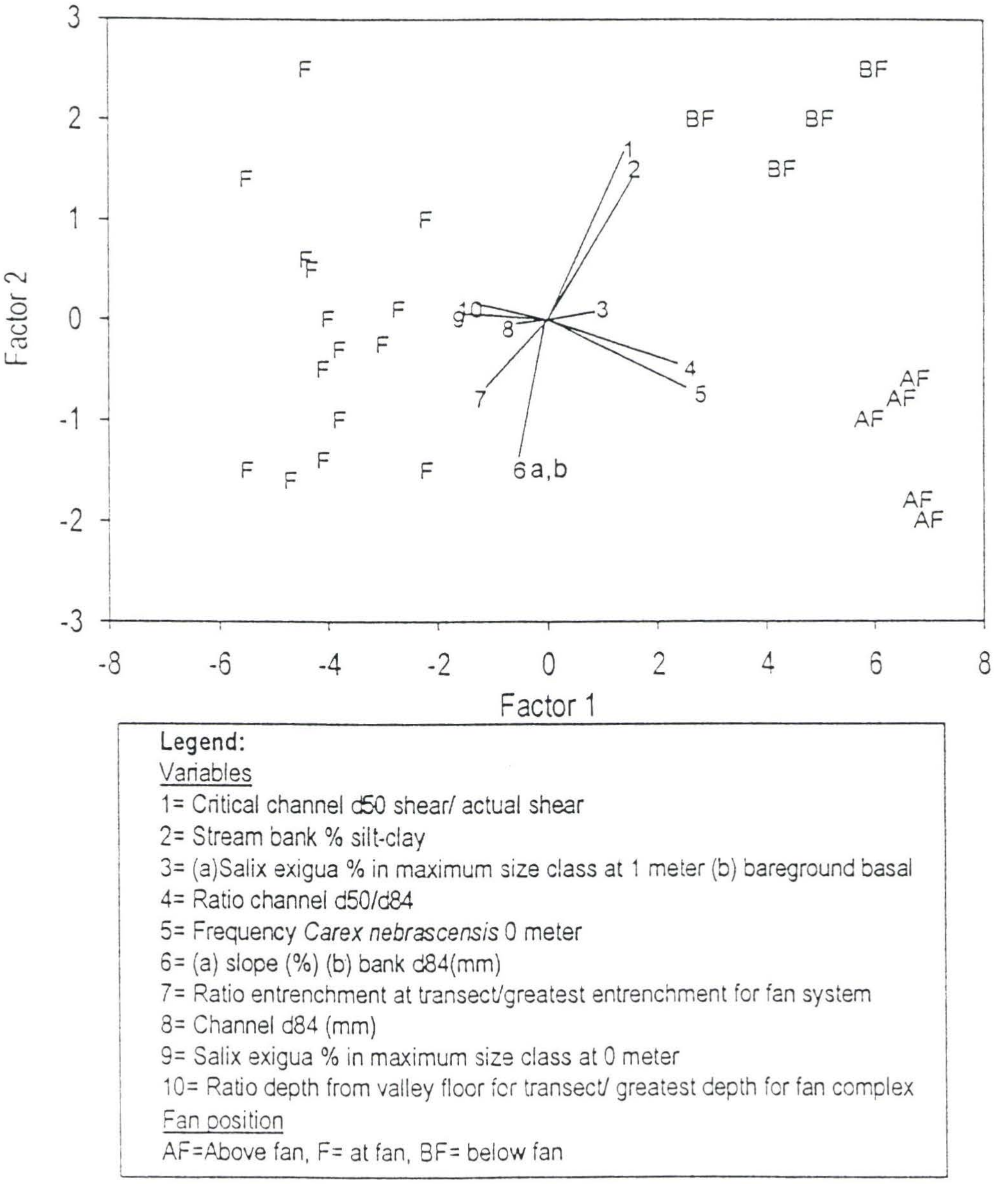


Figure 13. Discriminant function analysis scatter plot for 1999 all sites. Distribution of fan positions shown as points. Environmental and vegetation characteristics used as re-grouping variables. Vectors show how each variable contributes to discriminant factors 1 and 2.

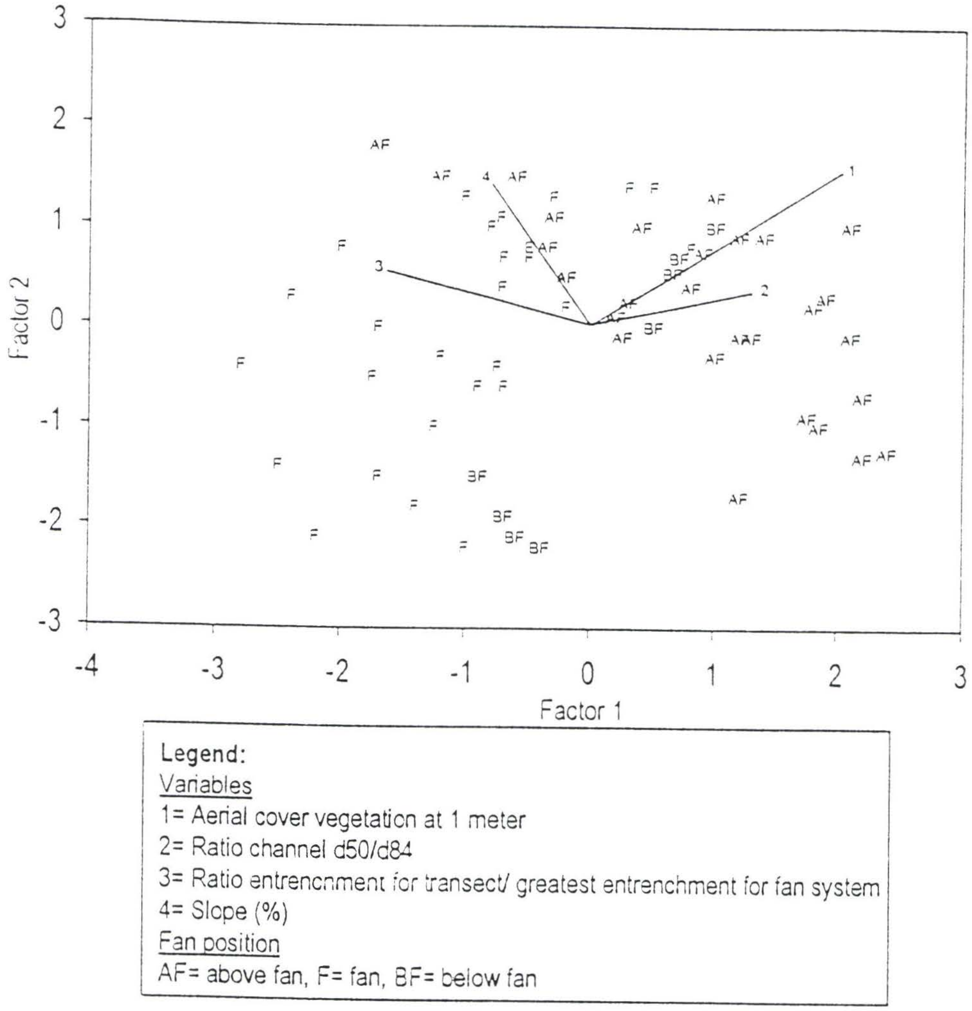
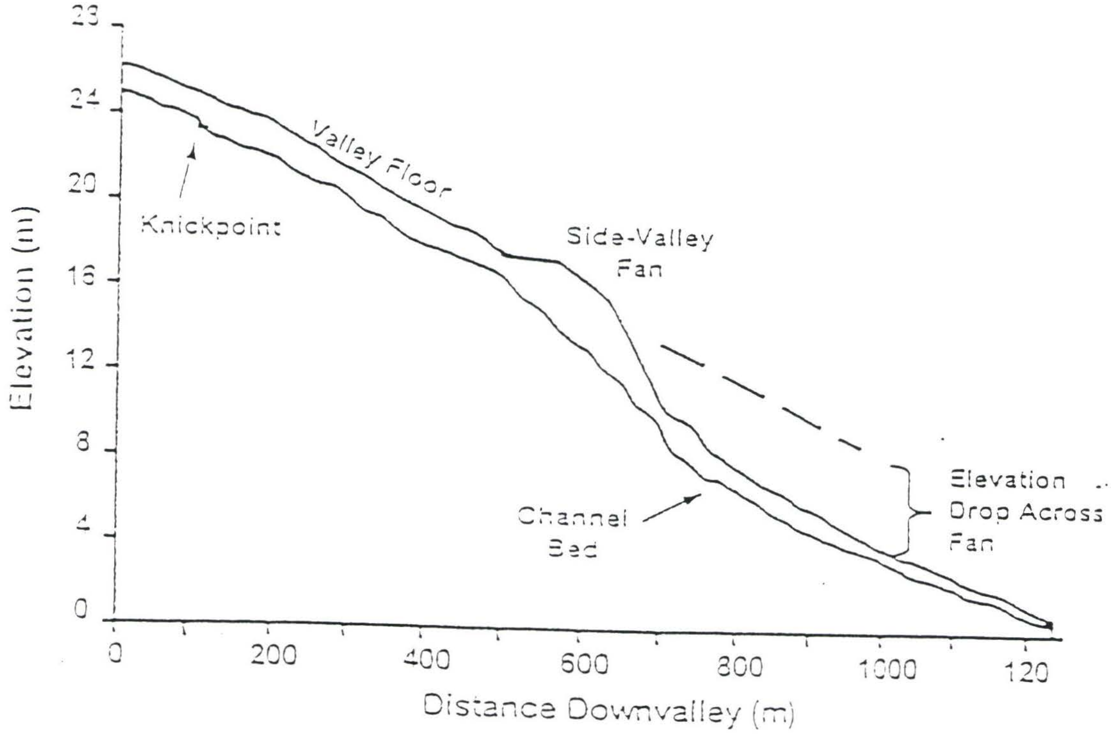


Figure 14. Longitudinal profile of hypothetical fan showing steep drop across the alluvial fan.



Appendix 1. Pearson Correlation coefficients (r),for 1998 sites. Includes geomorphic, hydrologic, willow and total cover data.

	d84 (n=38)	d50 (n=38)	Ht. 1st Terrace (n=38)	Area at measured peak (n=37)	Depth at measured peak (n=37)	Wdth/dpth at measured peak	Depth valley floor (n=43)	Bank% silt-clay (n=43)	Bank d84 (n=43)	Bank d50 (n=43)	Bank d50/d84 (n=43)	Area estimated highflow (n=40)	Area chge 95-98(hf) (n=15)	Dpth chge 95-98(hf) (n=15)	Depth estimated highflow (n=40)	Channel d50d84 (n=38)	Q unit width at measured peak (n=37)	Q at measured peak (n=37)	Veg. aerial cvr. 0m (n= 42)	Veg. base cvr. 0m (n=43)	Litter Aerial cvr. 0m (n=42)	Gravel base cvr. 0m (n=43)	Rock base cvr. 1m (n=43)	Veg. aerial cvr. 2m (n=43)	Litter base cvr. 2m (n=43)	Bnch Willow den 0m (n=43)	Bnch Wil mx dia.2m (n=43)	Bnch Wil mx ht. 2m (n=43)	Sal exi mx diam 0m (n=43)	Sal exi % int. 2m (n=43)	Sal exi mx ht. 2m (n=43)	Bnch wil % max.1m (n=43)	Bnch wil % min. 1m (n=43)	Depth bf/dpth valley (n=40)
d84	1																																	
d50	0.54**																																	
Ht. 1st Terrace	-0.53**	-0.23																																
Area at measured peak	-0.43*	0.01	-0.01																															
Depth at measured peak	-0.59**	-0.04	0.25	0.72**																														
Wdth/dpth, measured peak	.36*	-0.26	-0.2	-0.07	-0.60**																													
Depth valley floor	-0.34*	0.1	0.06	.51**	0.43**	-0.34*																												
Bank % silt-clay	-0.56**	-0.46**	.39**	.44**	0.14	0.26	0.15																											
Bank d84	.72**	0.32	-0.46**	-0.62**	-0.45**	0.02	-0.36*	-0.69**																										
Bank d50	.51**	.60**	-0.44**	-0.3	-0.06	-0.23	0.15	-0.64**	0.71**																									
Bank d50/d84	0.34*	0.54**	-0.36*	0	0.07	-0.32	0.25	-0.58**	0.56**	0.95**																								
Area estimated highflow	-0.40*	0.08	0.13	.66**	0.47**	-0.22	0.61**	0.08	-0.62**	-0.22	-0.18																							
Area chge 95-98(hf)	-0.51	-0.06	.59*	0.61*	0.59*	-0.71**	-0.14	0.14	-0.71**	-0.19	0.14	0.18																						
Depth chge 95-98(hf)	-0.23	0.28	.52*	0.67**	0.57*	-0.67**	-0.15	-0.14	-0.62*	-0.03	0.27	0.43	0.84**																					
Depth estimated highflow	-0.39*	0.16	0.06	0.58**	0.62**	-0.52**	0.56**	0.00	-0.38*	0.03	0.14	0.73**	0.15	**0.70																				
Channel d50d84	-0.23	0.68**	0.18	.39*	0.46**	-0.61**	0.40*	-0.09	-0.24	0.26	0.34*	0.43**	0.39	0.62*	0.5**																			
Q unit width, measured peak	-0.43*	0.11	-0.03	0.21	0.67**	-0.69**	0.33*	-0.29	0.07	0.41*	0.56**	0.09	0.56*	0.52*	0.49**	0.50**																		
Q at measured peak	-0.41*	0.1	-0.5	0.61**	0.73**	-0.47**	0.50**	0.09	-0.16	0.29	0.37*	0.33*	0.53*	0.52*	0.65**	0.48**	**0.84																	
Veg. aerial cvr. 0m	-0.06	0.24	0	0.05	0.28	-0.33	0.25	0.14	0.15	0.42**	0.49**	-0.39*	0.03	0.06	0	0.33*	0.48**	0.45**																
Veg. base cvr. 0m	-0.06	-0.25	0.28	-0.28	-0.29	0.29	-0.22	*0.33	-0.20	-0.50**	-0.55**	-0.06	-0.27	-0.39	-0.41**	-0.25	-0.56**	-0.54**	-0.27															
Litter Aerial cvr. 0m	-0.32	0.03	0.18	0.32	0.30	-0.22	-0.16	0.04	-0.18	-0.13	-0.11	0.24	0.38	0.21	0.32*	0.35*	0.22	0.19	-0.20	-0.04														
Gravel base cvr. 0m	0.24	-0.06	-0.16	-0.32	-0.18	-0.09	-0.31*	-0.38*	0.27	0.01	-0.01	-0.07	0.17	0.24	0.02	-0.28	0.03	-0.12	-0.47**	-0.06	-0.01													
Rock base cvr. 1m	0.44*	-0.16	-0.3	-0.37*	-0.41**	0.56**	-0.60**	-0.17	0.41**	0.08	-0.03	-0.52**	-0.53	-0.55*	-0.58**	-0.54**	-0.31	-0.30	-0.17	0.07	-0.18	0.32*												
Veg. aerial cvr. 2m	-0.26	0.12	-0.01	.53**	0.22	-0.17	0.34*	0.56**	-0.51**	-0.24	-0.16	0.27	0.27	0.58*	0.38*	0.35*	0.16	0.48**	0.27	-0.11	-0.03	-0.22	-0.37*											
Litter base cvr. 2m	-0.49**	-0.11	0.14	.36*	0.25	-0.13	-0.06	0.25	-0.29	-0.17	-0.13	0.16	0.70**	*0.62	0.21	0.32*	0.23	0.35*	0.08	0	0.41**	-0.12	-0.18	0.45**										
Bnch Willow den 0m	0.18	-0.12	0.1	-0.39*	-0.30	0.18	-0.56**	-0.06	0.05	-0.35*	-0.41**	-0.29	-0.16	-0.34	-0.43**	-0.30	-0.50**	-0.65**	-0.35*	0.35*	0.10	0.1	0.23	-0.43**	-0.24									
Bnch Wil mx diam 2m	-0.26	-0.08	0.16	0.04	0.45**	-0.46**	0.17	-0.22	0.05	0.14	0.24	0.08	0.49	0.40	0.26	0.19	0.61**	0.42*	0.25	-0.12	-0.12	0.09	-0.11	-0.18	-0.04	-0.30								
Bnch Wil mx ht. 2m	-0.28	-0.05	0.28	0.06	0.46**	-0.48**	0.38*	-0.20	-0.06	0.13	0.22	0.30	0.49	0.37	*0.38	0.25	0.52**	0.46**	0.16	-0.2	-0.06	0.1	-0.22	-0.06	0.07	-0.34*	0.77**							
Sal exi mx diam 0m	0.1	-0.24	-0.13	0.2	-0.1	0.17	0.15	0.30	-0.01	0.14	0.11	-0.02	-0.01	-0.34	0.04	-0.17	0.11	0.37*	0.21	-0.20	-0.08	-0.20	0	0.17	0.1	-0.42**	0.08	0.1						
Salix exigua % int. 2m	-0.08	0.23	0.14	.39*	0.20	-0.09	0.46**	0.34*	-0.31	0.11	0.1	0.28	-0.09	0.08	0.20	0.30	0.03	0.24	0.28	-0.13	-0.15	-0.39**	-0.28	0.44**	0	-0.37*	-0.11	0	0.29					
Salix exigua mx ht. 2m	0.09	.39*	.39*	.41*	.20	-0.13	0.42**	0.26	-0.07	0.35*	0.33*	0.17	0.12	0.26	0.26	0.33	0.08	0.39*	0.46**	-0.14	-0.09	-0.33*	-0.25	0.59**	0.18	-0.52**	0.00	0.16	0.39*	0.70**				
Bnch wil % max. 1m	-0.1	-0.12	-0.17	-0.03	0.07	-0.29	-0.15	-0.37*	0.24	0.19	0.16	0.03	-0.05	-0.15	0.1	-0.05	0.13	0.12	-0.14	-0.31*	0.1	0.20	0	-0.35*	-0.01	-0.1	0.29	0.04	0.08	-0.41**	-0.33*			
Bnch wil % min. 1m	0.15	-0.12	-0.01	0.06	0	0.07	0.18	-0.34*	0.26	0.19	0.08	0.21	-0.52*	-0.66**	0.00	-0.19	0	0.02	-0.80	-0.06	0.07	-0.10	-0.09	.43**	-0.29	0.03	0.05	0.50	0.09	-0.06	-0.15	0.17		
Depth bf/dpth valley	-0.17	0.16	0	0.26	0.28	-0.32*	0.02	-0.15	-0.27	-0.04	0.06	0.41**	0.49*	0.63**	0.65**	0.31	0.30	0.34	-0.27	-0.30	0.32	0.29	-0.23	0.27	0.23	-0.08	0.11	0.09	-0.20	-0.01	0.03	0.08	-0.19	1

* p<.05, **p<.01

Appendix 2: Twinspan two-way ordered table for 1998 nested rooted frequency data at 0 meter from streambank.

```
Cutoffs: 1=0.00, 2=.17, 3=.34, 4=.51, 5=.71
GROUPS:
+(KC)      -(MV,BCL3,SBL3)      #(ATU,ATL)
*(WCU3,WCL,SJU1,2,SJL3,CW1,3,SBU,SBL2)      !(BCM2,WCU2,SJU3,SJL1)
•(BCL1,2,BCM1,3,SJL2,CW2)      ^(BL)
--------------------------------------------------------------------------

                               +++-----#####***************!!!!!••••••^^^^
                                  222 43232311111123442233 1114 2    23333
   Genus species               1235676308293670234541021289818914057934567
--------------------------------------------------------------------------
   Juncus balticus             -----1-------------------------------------  000000
   Phalaris arundinacea        325----------------------------------------  000000
   Juncus nevadensis           ---534--------------------1----------------  000000
   Carex douglasii             ---3---------------------------------------  000000
   Geranium richardsonii       ------3------------------------------------  000000
   Mentha arvense              -1-33331--------11-------------------------  000000
   Veronica americana          --1----------------------------------------  000000
   Artemisia tridentada        -------2---------------1-------------------  000000
   Melilotus officinale        ---3-32----------------------------222-----  000001
   Sidalcea oregan             2---2332-3-2---------1---------------2-----  000001
   Trifolium wormskijoldii     -2-333--3--1---1----1----1--2----1--1------  000001
   Viola spp.                  -1--1212--------2-----------111-----11-----  000001
   Carex nebrascensis          22---1-------------1------11---------------  000010
   Salix exigua                -22322-------22-------2-----2-2------------  000010
   Carex praegracilis          ----21-1------------1------12--------------  000011
   Equisitum arvense           243554--2--1---5424534-------5-------------  000011
   Rorripa nasturtium-aq.      -------3-------------------2---------------  000011
   Agrostis stolonifera        --254553--1----322313--2-22153332343553----  00010
   Mimulus guttatus            ---22---1-------------------1-12-1---------  00010
   Carex microptera            -----2--4----------------------2-----------  00011
   Aster spathulus             --13211-3-13322------1----1-----------1----  00011
   Equisitum laevigatum        ------3--212--------1------------1-1131----  001000
   Arnica chamissonis          ------2----------------------------2-25----  001000
   Agropyron intermedium       -------------1------------------1---22-----  001001
   Agropyron cristatum         -----------------------------------2-------  001001
   Bromus tectorum             ------------------------------2---1--------  001001
   Aquilegia formosa           -------------11--1-----------2-------------  001001
   Carduus nutans              ------------------------------2------------  001001
   Iva axillaris               -------------1------------------------1----  001001
   Medicago lupulina           ------------------1----------2---2-2-1-----  001001
   Urtica dioica               -----------------------------2---1---------  001001
   Stellaria longipes          ---------2--------1--2----1-32-1-1---------  001001
   Collinsia parviflora        -------------------------------------2-----  001001
   Rosa woodsii                ------------------------------2-1----------  001001
   Salix lutea                 ---------21-2------------1---352------3----  001001
   Stipa comata                ------------------------22-----------------  001010
   Carex spp.                  --------2-----------2----------------------  001010
   Carex aurea                 ---------------------1---------------------  001010
   Carduus nutans              ------------------------11-------1---------  001010
   Artemisia michauxiana       -----------------2--2----------------------  001010
   Cerastium fontanum          ---------------32------------1-------------  001010
   Geum macrophyllum           -----------------2-------------------------  001010
   Lupinus argenteus           -------------111---------------------------  001010
   Rannunculus cymbalaria      -------------------1---2--11--11-----------  001010
   Triflium monanthum          --------1-1-1-----11-----21-----1----------  001010
   Verbascum thapsis           --------1------1-1----------1--------------  001010
   Achillea millifolium        ---211---1--35531133-31-11----512---12-----  001011
   Iris missouriensis          ---2----1----1-11-----2-1111---------------  001011
   Triflium longipes           ---3---1---2242--22-------454--------------  001011
   Senecio hydrophilus         13----3-11-222213333-33-32222221-2-313--3--  00110
   Cicuta douglasii            ----1-11114-2211133332352122333151-21-12---  00110
```

Appendix 2 continued:

```
Poa pratensis           23234354555554553555554334555534343555532-2  00111
Artemisia ludoviciana   ----------------1-11--------1-------------1  010
Taraxicum officinale    ------------1--22--1--13-1-112--3--1-11-233  010
Deschampsia caespetosa  ---2-2--53544--12--1-3-1---1------------32-  011
Juncus ensifolius       ---------------------------2----------3-2--  1000
Carex athrostachya      -------------------------------1-1-----2---  1001
Juncus buffonius        ----------------------------------1-----3--  1001
Leymus triticoides      -----------------2---------------------3--2  10100
Juncus longistylis      ---------------------1----11-----------23-1  10100
Muhlenbergia richardsonis---------------------------------------3--  101010
Eleocharis macrostachya -----1---------------1-----------------322-  101010
Potentilla glandulosa   ----------------------------------------2-1  101010
Salix lutea x boothii   ---------------------------------------333-  101010
Agrostis stolonifera    ------------------------------------------2  101011
Conyza canadensis       ------------------------------------------4  101011
Descurania sophia       ------------------------------------------2  101011
Viola paulstris         ------1---------------------------------2--  10110
Polygonum bistortoides  -------1------1--------------------------2-  10110
Artemisia ludoviciana   -------1-----------------------------1-2---  10111
Juncus balticus         ---2-5--22-1--------1----1-1----------12--1  110
Epilobium glaberrimum   -11-33------11--1-1-1--1--1------------2322  1110
Carex lanuginosa        ---233----------1-----11---1------------222  1111
Gnaphalium palustre     -1----------------------------------------1  1111
                        0000000000000000000000000000000000000001111
                        0000000011111111111111111111111111111110001
                        000111110000000000000000000011111111111011
                        011000110000011111111111111100000111111
                        011  0111100111111111111100111000001
                        0011  0000000001111  01100111
```

Appendix 3: Twinspan two-way ordered table for 1998 nested rooted frequency data at 1 meter from streambank

```
CUTOFFS: 1=0.00, 2=.17, 3=.34, 4=.51, 5=.71
GROUPS:
+(BL)      -(MV,ATU2)       #(ATU1,3, ATL, CW2,3,SBU3,SBL3)
*(WCU,WCL1,3,SBU1)          !(KC,SBU2)      ^(BCL,BCM,SJU1,SJL2)
•(WCL2,SJU2,3,SJL2,3,SBL1,2,CW1)

                         ++----#########******!!!!^^^^^^^^••••••••++
                         333222222233344111113   311      1112244233
Genus species            6706753489123030123581239695789464780112245
Carex lanuginosa         52-22-----------------23------------------3 1111
Conyza canadensis        35----------------------------------------3 1110
Carex athrostachya       5----------------------------------------33 1110
Epilobium glaberrimum    ----2--------22---------52---------------53 1101
Potentilla glandulosa    ------------------------2----------------5- 1101
Veronica peregrina       -----------------------------------------3- 11001
Polygonum bistortoides   -----------------------------------------3- 11001
Agrostis scabra          -------------2---------------------------53 11000
Artemisia ludoviciana    ----------------23---------------2-------3- 10
Aster spathulus          -5-4433352--22----------------------------- 0111
Juncus balticus          -54225322-4-------------------------------- 0111
Taraxicum officinale     3--2-3-422-2-2-4-3----222-------2---------- 0110
Carex nebrascensis       -2-------------------4--------------------- 0110
Phlox spp.               --2---------------------------------------- 010111
Viola spp.               ---433------------------------------------- 010111
Mentha arvense           ---435---------------2--------------------- 010111
Juncus nevadesis         ---433------------------------------------- 010111
Carex praegracilis       ---2-3------------------------------------- 010111
Glyceria elata           -----3------------------------------------- 010111
Trifolium wormskijoldii  ---543-22------------4--------------------- 010110
Arnica chamissonis       --2------------2--------------------------- 01010
Geum macrophyllum        ----2--------1---2------------------------- 01010
Cicuta douglasii         -----32242--232223-32442422------2--------- 01001
Equisitum arvense        ---55522--2----25233-44-------------------- 01001
Ribes inerme             --------------------2-2-------------------- 010001
Senecio hydrophilus      ---------------------23-------------------- 010001
Medicago lupulina        -----------------2------------------------- 010001
Geranium richardsonii    ----------------------22------------------- 010001
Juncus spp.              ---------------2--------------------------- 010001
Carex microptera         -----------------------2------------------- 010001
Poa palustris            -----------------------2------------------- 010001
Phalaris arundinacea     ---------------------2-5------------------- 010001
Artemisia tridentada     ----------22-21---------------------------- 010000
Stellaria longipes       -------2----------------------------------- 010000
Trifolium longipes       ------5------------------------------------ 010000
Cirsium drummondii       ----------2-------------------------------- 010000
Iris missouriensis       ---------2--------------------------------- 010000
Trifolium monanthum      ------25---2------------------------------- 010000
Mimmulus guttatus        -------------1----------------------------- 010000
Cerastium fontanum       -------2----------------------------------- 010000
Carex jonesii            -------2----------------------------------- 010000
Carex aurea              ---------2--------------------------------- 010000
Deschampsia caespetosa   -----3--25--------------------------------- 010000
Salix lutea x boothii    -2----------------------------------------- 00111
Gnaphalium palsutre      -2----------------------------------------- 00111
Leymus triticoides       -2--------------------2-------------------- 00110
Salix exigua             -----3--------1-22---4-54--------53-------- 00101
```

Appendix 3: Continued

```
Aquilegia formosa         ---------------232---------------22--------  00101
Poa pratensis             --5-5554554253155555555544545453553322-2---  001001
Agrostis stolonifera      ---5553222--2-1222-3--232-----4-5-----2----  001001
Equisitum laevigatum      ---22--2-4-2-------------------23----------  001000
Carduus nutans            ---------------432-------------22-2--------  00011
Artemisia michauxiana     -----------------2---------------2---------  00010
Achillea millefolium      -------2---2----2---222222-------3-3--2----  00010
Chrysnothamnus nauseosus  ------------2----------------2-------------  000011
Carex douglasii           ---2---------21-----------4----------------  000011
Erigeron lonchophyllum    --------------------------------2----------  000010
Melilotus officinale      ---------------------------424555----------  000010
Bromus tectorum           -----------------------------4-------------  000010
Muhlenbergia richardsonis--------------------------------2----------  000010
Agropyrom intermedium     -------------------------22252-------------  000010
Salix boothii             ---------------------------------2---------  000001
Rosa woodsii              -----------------------------------3-------  000001
Tragapogon dubius         ----------------------------------2--------  000001
Verbascum thapsis         ----------------------------------2--------  000001
Rannunculus cymbalaria    -----------------------------------2-------  000001
Zigadenus paniculata      --------------1------------------223-22----  000001
Salix lutea               --2---342-----1-----------2--2----2--22-5--  000000
                          0000000000000000000000000000000000000000011
                          00111111111111111111111111111111111111111
                          000000000000000000000001111111111111111
                          000011111111111111111110000000011111111
                          011100000000011111111110000011100000001
                          0010000000110000000111100111011001111
```

Appendix 4. Twinspan two-way ordered table for 1998 nested rooted frequency data at 2 meters from streambank.

Cutoff values: 1= 0.0, 2=.17, 3=.34, 5=.51, 5=.70

GROUPS:

```
+ (BL1,2,3,4,ATL1)       # (KC,WCU, WCL1,2,ATU2)      ^ (SBL)
- (ATU3,BCL,BCM, ATU1)   * (WCL3,SJL,CW,MV3,ATL3)
```

```
                            +++++--------#########*********^^^
                            222332    2   2  11111111112222333
                            8960154568379142301234576890712234
Genus species
Iva axillaris               -------------------------------2-5  1
Epilobium glaberrimum       -----------------------------3-2--  0111
Salix exigua                -------------3--2--------------24-  01101
Hackelia floribunda         --------------------------------2-  01101
Chrysnothamnus nauseosus    -3-----------------------------22-  01100
Senacio hydrophilus         -3-------------3------------------  010111
Conyza canadensis           ----2-----------------------------  010110
Artemisia ludoviciana       ---34---2---------3---------------  010110
Leymus triticoides          -35542--------4------2------------  010110
Salix lutea x boothii       3---------------------------------  010101
Potentilla glandulosa       -3------------2-------------------  010101
Eleocharis pauciflora       -3--------------------------------  010101
Carex lanuginosa            35-3-------------------------53---  010100
Aster spathulus             ---3---------32-----------45-3----  0100
Equisitum arvense           -3--------------2----------3-53---  0100
Tragapogon dubius           ------------3---------------------  001111
Agropyron intermedium       -----2-----53---------------------  001111
Chrysnothamnus viscidiflorus-----4----------------------------  001110
Triflium longipes           ----------3-----------------------  001101
Verbascum thapsis           --------2-------------------------  001101
Melilotus officinale        ------4445--3---------------------  001101
Leymus cinereus             --------2-------------------------  001101
Equisitum laevigatum        --------4-3----------------2------  001100
Artemisia tridentada        -----2--------2-------------------  00101
Gayophytum racemosum        -----2--------2-------------------  00101
Poa secunda ssp. juncifolia -----2--------2-------------------  00101
Poa pratensis               -----2423-353545553545555255535---  00100
Ribes inerme                ---------------3------------------  000111
Symphoricarpus oreophilus   ---------------------2------------  000111
Artemsia michauxiana        --------------------435-----------  000111
Aquilegia formosa           ------------------3---------------  000111
Carex nebrascensis          ---------------3------------------  000111
Bromus madritensis          ---------------3------------------  000111
Phalaris arundinacea        -------------3-3------------------  000110
Mentha arvense              ---------------3-------------3----  000101
Taraxicum officinale        -------------34---------2--3------  000100
Arnica chamissonis          --------------2---------2---------  000100
Cicuta douglasii            -------------3--2-3-----4-2-------  000100
Achillea millifolium        ----------------3---2---4-43--3---  000011
Salix lutea                 ------------------------23235-----  000010
Viola spp.                  -----------------------------35---  000010
Trifolium monanthum         --------------------------22------  000010
Trifolium wormskijoldii     -----------------------------3----  000010
Rannunculus cymbalaria      -----------------------------3----  000010
Geum macrophyllum           ------------------------2-2-------  000010
Cerastium fontanum          --------------------------2-------  000010
Carduus nutans              ------------------3------2----3---  000010
Juncus nevadensis           -----------------------------5----  000010
Juncus balticus             ---------------------------2--5---  000010
Carex douglasii             ------------------------2---------  000010
```

Appendix 4 continued

```
Bromus tectorum             ---------------------------2------  000010
Deschampsia caespitosa      -----------------------------3----  000010
Agrostis stolonifera        --------25---32---------2-53555---  00000
                            0000000000000000000000000000000001
                            000000000000000000000000000000011
                            0000011111111111111111111111111
                            0011100000000111111111111111111
                            01101111111000000000001111111
                            0000011001111111110000011
```

Appendix 5. Linear regression results for the 1998 vegetation data vs. geomorphic and willow data. Reciprical Averaging axes from nested rooted frequency data (at 0, 1 and 2 meters from stream) as dependent variables.(n=20 to n=41)

	0 meter			1 meter				2 meter			
	Axis 1		Axis 2	Axis 1		Axis 2		Axis 1		Axis 2	
Variable	R^2	+/-	R^2	R^2	+/-[1]	R^2	+/-[1]	R^2	+/-[1]	R^2	+/-[1]
Bank d50 (b50)								0.27**	-	NS	
Bank d65 (b65)				0.16**	-	0.16**	-				
Bank d84 (b84)				ns		0.31**	-	0.4**	+	0.15*	-
Bank d50/bank d84				0.14*	-	0.23**	-				
% silt-clay banks	NS		NS	0.15*	+	0.26**	+	0.22**	+	0.23**	+
Critical q bank d84	NS		NS								
Critical q bank d65				0.16*	-	0.27**	-				
Critical q b50/q at peak flow	0.12**	+	NS								
Critical q b84/q at peak flow								0.15*	-	NS	
Critical q d50/q at peak flow	0.29**	+	NS								
Area bankfull								0.29**	+	NS	
Area high flow (estimated)	NS		NS					NS		NS	
Width bankfull				ns		0.23**	+	0.19*	+	NS	
Depth at peak flow				0.15**	-	ns					
Width/depth at peak flow				0.35**	+	0.11*	+				
Discharge per unit width (q)	0.16**	+	ns	0.28**	-	0.3**	-	0.05		0.24*	-
Depth from valley floor	NS		NS					NS		0.06	
Bunch willow density 0m	NS		NS	NS		NS		0.25**	+	ns	
Salix exigua density 0m	NS		NS	0.17**	+	NS		NS		NS	

*P<.1, **P<.05, ***P<.01

[1] slope positive/negative for significant relationships only

NS= not significant

Appendix 6. Pearson correlation coefficients (r), for 1999 data. Includes fan position, geomorphic, willow, cover and vegetation data.

	Fan position	Ht. 1st Terrace	Depth valley floor	Ratio depth vly flr.	Ratio entrenchment	Slope (%)	% silt-clay banks	Channel d84	Channel d50	Bank d50	Bank d84	Bank d50/channel d50	Bank d84/channel d84	Bank d50/d84	Channel d50/d84	Critical shear b50/shear	Crtical shear b84/shear	Crtical shear d84/shear	Salix exig. % max. 0 m	Salix exig den. 0 m	Salix exig. Mx. Ht. 0 m	Salix exig. % max. 1 m	Bnch will. % mx. 1m	Bare 0 basal cover	Litter aerial cover 1 m	Veg. aerial cover 1 m	Veg. aerial cover 0 m	Wetland spp. 0 m	Wetland spp. 1 m	Upland spp. 1 m	Carex nebrascensis 0 m	Carex nebrascensis 1 m	Cicuta douglasii 1 m	Cicuta douglasii 0 m	Bnch will. % mx. 0m
Fan position	1																																		
Ht. 1st Terrace	-0.25*																																		
Depth valley floor	-0.2	0.31*																																	
Ratio depth vly flr.	0.14	0.29*	-0.00																																
Ratio entrenchment	0.19	-0.09	-0.30*	0.73**																															
Slope (%)	-0.03	0.09	-0.08	-0.05	-0.02																														
% silt-clay banks	-0.16	-0.15	0.24	-0.38**	-0.31*	-0.12																													
Channel d84	0.1	0.15	-0.18	0.23	0.23	0.13	-0.36**																												
Channel d50	-0.05	0.07	-0.16	-0.06	-0.06	0.35**	-0.44**	0.62**																											
Bank d50	-0.05	0.28*	0.03	0.15	0	0.07	-0.45**	0.16	0.22																										
Bank d84	-0.03	0.28*	-0.12	0.17	-0.03	0.23	-0.56**	0.22	0.38**	0.82**																									
Bank d50/channel d50	0.01	0.11	-0.19	0.09	0.08	0.09	-0.34*	-0.1	-0.09	0.86**	0.69**																								
Bank d84/channel d84	-0.04	0.04	-0.22	0.06	-0.02	0.03	-0.33*	-0.36**	-0.12	0.56**	0.70**	0.71**																							
Bank d50/d84	-0.04	0.24	-0.05	0.14	0.06	0.05	-0.4*	0.16	0.22	0.92**	0.67**	0.76**	0.43**																						
Channel d50/d84	-0.25*	-0.14	-0.05	-0.23	-0.22	0.07	-0.03	-0.55**	0.18	-0.08	0.06	0.01	0.43**	-0.11																					
Critical shear b50/shear	0.01	0.34**	-0.09	0.24	0.25*	0.02	-0.16	0.36**	0.13	0.06	0.08	0.01	-0.01	0.12	-0.18																				
Crtical shear b84/shear	0.06	0.15	0.04	0.01	-0.1	0	-0.21	-0.01	-0.02	0.72**	0.60**	0.71**	0.59**	0.65**	-0.06	-0.04																			
Crtical shear d84/shear	0.25*	0	-0.19	0.26*	0.31*	0.09	-0.15	0.28*	0.15	-0.07	-0.07	-0.09	-0.23	0.02	-0.17	0.10	-0.13																		
Salix exig. % max. 0 m	0.32*	-0.24	-0.09	0.07	0.04	0.02	-0.03	0.27*	0.1	-0.11	-0.05	-0.16	-0.2	-0.12	-0.16	0.15	-0.09	0.03																	
Salix exig den. 0 m	0.32*	-0.23	-0.1	0	-0.09	-0.04	0.1	0.17	0.06	-0.21	-0.05	-0.17	-0.14	-0.24	-0.09	0.2	-0.12	-0.01	0.70**																
Salix exig. Mx. Ht. 0 m	0.39**	-0.13	-0.13	0.01	-0.05	0.06	-0.01	0.14	0.1	-0.02	0.05	-0.02	-0.08	-0.01	-0.08	0.26*	-0.07	0.09	0.77**	0.82**															
Salix exig. % max. 1 m	0.24	-0.25	-0.06	0.04	0.16	0.05	0.01	0.24	-0.02	-0.12	-0.14	-0.09	-0.22	-0.14	-0.3**	-0.03	-0.09	0.1	0.66**	0.38**	0.40**														
Bnch will. % mx. 1m	0.1	0.06	0.07	0.06	0.15	0.07	-0.18	0.03	-0.11	0.13	0.04	0.07	-0.06	0.12	-0.19	-0.19	0.1	0.18	-0.11	-0.25*	-0.09	-0.07													
Bare 0 basal cover	-0.04	-0.18	0.33*	-0.17	-0.15	-0.13	0.42**	0.08	-0.25	-0.29*	-0.42**	-0.27*	-0.45**	-0.27**	-0.37**	-0.05	-0.06	-0.13	0.21	0.25	0.11	0.12	0.1												
Litter aerial cover 1 m	0.25*	-0.11	-0.15	-0.02	0.03	-0.08	-0.17	0.08	-0.11	0.1	0.05	0.1	0.05	0.07	-0.16	-0.14	0.1	0.07	0.17	0.04	0.07	0.19	0.44**	-0.03											
Veg. aerial cover 1 m	-0.41**	0.29	0.20	-0.06	-0.1	-0.09	0.22	-0.06	-0.13	0.19	-0.05	0.13	-0.08	0.23	-0.09	-0.03	0.19	0.06	-0.4**	-0.46**	-0.46**	-0.15	-0.04	0.2	-0.31*										
Veg. aerial cover 0 m	0.01	-0.08	-0.02	-0.22	-0.13	0.04	0.25*	-0.42**	-0.14	-0.11	-0.13	0.02	0.13	-0.09	0.28*	-0.13	-0.12	-0.21	-0.34*	-0.23	-0.19	-0.28	-0.29*	-0.24	-0.18	0.08									
Wetland spp. 0 m	0.08	-0.25	-0.06	0.04	0.19	-0.1	0.08	-0.28*	-0.17	-0.13	-0.07	-0.04	0.13	-0.09	0.15	-0.21	-0.12	-0.02	-0.03	-0.03	-0.02	-0.02	0.06	-0.15	-0.17	-0.13	0.48**								
Wetland spp. 1 m	-0.24	0.07	0.22	-0.06	-0.04	-0.28*	0.41**	-0.21	-0.38**	-0.19	-0.29*	-0.11	-0.08	-0.05	-0.13	-0.25	-0.1	-0.1	-0.22	-0.15	-0.27*	-0.09	0.07	0.28*	-0.18	0.3*	0.08	0.25*							
Upland spp. 1 m	-0.14	0.2	-0.18	0.09	0.1	0.31*	0	0.1	0.19	-0.19	-0.03	-0.17	-0.02	-0.13	0.19	0.18	-0.21	-0.1	0.07	-0.08	-0.07	0.02	-0.16	-0.27	0.1	-0.06	0.27*	0.17	0.01						
Carex nebrascensis 0 m	-0.4	0.25	0.24	-0.31*	-0.44**	0.01	0.38**	-0.19	-0.05	-0.09	-0.11	-0.04	-0.06	-0.09	0.22	-0.19	0.11	-0.18	-0.221	-0.12	-0.2	-0.19	-0.21	0.19	-0.27	0.37**	0.15	-0.07	0.34*	-0.03					
Carex nebrascensis 1 m	-0.41**	0.07	0.28	-0.36**	-0.39**	-0.1	0.37**	-0.19	-0.13	-0.15	-0.19	-0.12	-0.12	-0.12	0.16	-0.2	-0.07	-0.21	-0.24	-0.13	-0.24	-0.2	-0.13	0.29*	-0.2	0.33*	0.16	-0.02	0.51**	-0.06	0.81**				
Cicuta douglasii 1 m	0.11	-0.09	-0.39**	0.38**	0.41**	-0.17	-0.15	0.12	-0.06	0.03	0	0.09	0	0.17	-0.18	0	-0.04	0.2	0.09	0.05	0	0.06	-0.03	-0.21	0.06	-0.16	0.06	0.2	0.33*	0.23	-0.2	-0.16			
Cicuta douglasii 0 m	0.14	-0.19	-0.27*	0.2	0.21	-0.11	-0.36**	0.08	0.12	0.34*	0.37**	0.27*	0.3	0.32	-0.00	-0.04	0.11	-0.03	0.13	-0.08	0.08	0.12	0.03	-0.46**	0.11	-0.24	0.09	0.37**	-0.17	0.04	-0.39**	-0.33*	0.29*		
Bnch will. % mx. 0m	0.12	-0.05	-0.13	-0.04	0.04	-0.08	-0.21	0.22	-0.01	0.08	0.09	0.03	0.02	0.03	-0.15	0.08	0.03	0.05	0.1	-0.04	0.06	0.16	0.37**	-0.16	0.34*	-0.14	-0.17	0.09	-0.17	0.22	-0.31*	-0.29	0.02	0.16	1

* p< .05, ** p< .01

Appendix 7. Twinspan two-way ordered table for 1999 nested rooted frequency data at 0 meters from stream, fans with meadows.(values down-weighted). Wetland status left column, W= wet, I= intermediate, U= upland.

```
                        11     11322  2223313322  112311221333
  Genus species         12934253483717456370458968751189026026
W Salix boothii         ------------------------------------1-  11
W Unkown forb           ------------------------------------3-  11
W Rumex crispus         ------------------------------------1-  11
W Rorripa nast.-aqua.   ------------------------------------22  11
U Artemisia tridentada  ---------------4--------411---------32  10
I Poa pratensis         -1---332313234444421444344243442434--2  0111
W Carex nebrascensis    1-33244-----1-4313-1------------------  011011
W Carex urticulata      --2-----------------------------------  011010
W Phalaris arundinacea  43------------------------------------  011010
W Salix lutea           1---------------------3----------2----  01100
W Salix exigua          -2-----44--------------------2--------  01100
W Cicuta douglasii      --1--------------------1---1--324421--  01011
W Mimmulus guttatus     ------------------------1-1-----------  010101
U Melilotus officinale  ----------------------------1---------  010101
W Equisitum hymenale    -----------------1---------24-2-1-----  010101
W Deschampsia elongata  -----------------------------------1--  010101
W Agrostis stolonifera  -------------1--------233243444222----  010101
U Agropyron intermedium ------------2---------------------4---  010101
W Trifolium wormskijoldii------------------2--11----14--------  010100
W Deschampsia caespetosa-------------2----1-----1-------------  01001
W Moss                  ----------------------44--2-1---------  01001
W Epilobium ciliatum    --------1-----------------------------  010001
W Equisitum arvense     --------1----------3------------------  010001
I Elymus trachycaulus   --------1-----------------------------  010001
I Rosa woodsii          -------------3------------------------  010000
W Iva axillaris         ----------------1---------------------  010000
U Taraxicum officinale  --------------21----2-12--------------  010000
W Aster spathulus       ------------1--1121-2412--------------  010000
U Achillea millefolia   ---------------------111--------------  010000
W Juncus ensifolius     ---------------211-3331--------------1  00
                        00000000000000000000000000000000000011
                        000000011111111111111111111111111111
                        001111100000000000000000111111111111
                        0001100000111111111111000000000001
                        011  0011100000000001100000011111
                               0110000000111  00011100001
```

Appendix 8: Twinspan two-way ordered table for 1999 nested rooted frequency data at 0 meters from stream, fans without meadows,(values down-weighted).

```
                           111     111121 1   1
   Genus species           13435124968705807962
 U Artemisia ludoviciana   --2----------1------  000000
 W Veronica peregrina      12-----------1------  000000
 I Elymus trachycaulus     2-1-----------------  000001
 W Agrostis exarata        -1------------------  000001
 W Eleocharis macrostachya 1-1-----------------  000001
 W Mentha arvense          --1-----------------  000001
 W Arnica chamissonis      --1-----------------  000001
 W Veronica americana      --1-----------------  000001
 I Conyza canadensis       1-------------------  000001
 W Epilobium ciliatum      23-111--------------  00001
 I Rosa woodsii            --4-1-------1-------  00001
 W Carex lanuginosa        2-2-------1--4----11  0001
 W Salix lutea             3343-42-3-3--------3  0001
 W Agrostis stolonifera    --121463--1--------1  001000
 U Melilotus officinale    -----262------------  001001
 W Trifolium wormskijoldii -----12-------------  001001
 U Agropyron intermedium   ---4-2--------------  001010
 U Agropyron cristatum     ---32-12------------  001010
 I Urtica diocia           ----1---------------  001011
 U Crepis pleuocarpa       ---1----------------  001011
 I Populus tremuloides     ----2---------------  001011
 W Salix exigua            1--2--53322-36------  00110
 W Carex urticulata        -----------1--------  001110
 U Helianthus uniflora     ------------4-------  001110
 W Rannunculus cymbalaria  -------------1------  001110
 W Salix lutea x boothii   ------------1-------  001110
 W Carex microptera        ---------1----------  001111
 W Juncus ensifolius       --------11----------  001111
 W Carex spp.              --------1-----------  001111
 W Cicuta douglasii        --21132224526-14221-  010
 U Artemisia tridentada    -1--1211-3-522---24-  010
 U Taraxicum officinale    ---11---143111-2-115  0110
 I Poa pratensis           -1-446622532-245454-  0111
 W Mimmulus guttatus       -----1-------------1  0111
 U Achillea millefolia     1--------12-112-1-2-  100
 W Carex aurea             -------------1----1-  100
 U Lupinus argenteus       ---1----------1-----  101
 U Chrysnothamnus viscid.  ----1-1----13--41-1-  101
 W Carex athrostachya      --------------1-1---  110000
 W Juncus longistylis      --------------11-1-1  110000
 W Carex jonesii           -----------------1--  110000
 W Iris missouriensis      --------------1-----  110000
 W Trifolium variagatum    ----1---------4111-1  110000
 W Salix boothii           --------------62626-  110000
 W Deschampsia caespetosa  -21-------2---554451  110001
 W Carex nebrascensis      ------------------2-  110001
 W Equisitum arvense       ------------------2-  110001
 U Agropyron spp.          -------------------2  11001
 W Equisitum hymenale      -----11-------2-1432  11001
 W Aster spathula          -------------22---1-  11010
 W Juncus balticus         1-1------------11112  11010
 W Moss                    1-3--2132-4--56666-6  11011
 W Agrostis scabra         -11----------------2  111
 W Rannunculus aquatica    1------------------1  111
                           00000000000000111111
                           00011111111111000001
                           0110000011111100001
                              001110000010011
                                01100011
                                   011
```

Appendix 9. Twinspan two-way ordered table for 1999 nested rooted frequency data at 1 meter from stream, fans with meadows,(not downweighted). Wetland status given in left column: W= Wetlands, I= Intermediate, U= Upland.

```
                        3 2  111112223121121233233322      1
                        086676957810262934807145235341234591
U Phlox gracilis        --1------------1--------------------  111
W Mimmulus guttatus     3-------------1-1-------------------  1101
W Epilobium ciliatum    3---------------------1-------------  11001
W Barbarea orthocerus   1-----------------------------------  11000
W Sagina saginoides     2-----------------------------------  11000
W Chenopodium rubrum    1-----------------------------------  11000
W Unknown forb          1-----------------------------------  11000
W Rumex crispus         4-----------------------------------  11000
W Rorripa nasturtium-aq.1-----------------------------------  11000
U Bromus tectorum       -241---------------------11---------  10111
W Iva axillaris         --6---------------1-----------------  101101
U Lupinus argenteus     -1----------------------------------  101100
U Carex douglasii       --1---------------------------------  101100
I Festuca rubra         -1----------------------------------  101100
W Leymus triticoides    --2---------------------------------  101100
U Bromus carinatus      -2----------------------------------  101100
I Rosa woodsii          ----5-------------------------------  10101
U Camelina microcarpa   ----1-------------------------------  101011
U Polygonum douglasii   ---1--------------------------------  101011
U Galium aparine        ---1--------------------------------  101011
U Collomia linearis     ---1--------------------------------  101011
W Viola sororia         ---------1--------------------------  101010
W Urtica diocia         1-----1-----1-----------------------  101010
W Cicuta douglasii      -----21-1-------1-------------------  101010
U Melilotus alba        -----4-3313------------1----1-------  101010
U Equisitum hymenale    --1---221443---------21-------------  101010
U Agropyron cristatum   ------1---12------------------------  101010
W Glyceria elata        ------1--1--------------------------  101010
I Aquilegia formosa     -----1------------------------------  101010
U Agropyron intermedium 2---311531411----------------5--1---  10100
W Salix lutea           -2-------22-4-------5--------------3  1001
W Agrostis stolonifera  2---133124-----2--1-1------12-------  1001
I Cerastium glomeratum  -------1--------------------1-------  1000
W Veronica americana    2---------------------------------2-  0111
W Carex lanuginosa      ---------1----1-------------------11  0111
W Salix boothii         3--------------------12-------------  0110
I Poa pratensis         3663354436232-4252233633642666666614  0110
W Trifolium wormskijoldii----21---------1-2221-------------2  010
U Habeneria sparsiflora -1----3----11--2--23--1--2122-------  010
W Juncus balticus       --2--1-1-1------1114242325235--14313  00111
U Carduus nutans        --------1--------1------2--1----1---  00111
W Aster spathulus       ---111-1-2-----1312333232422--3211-1  00110
U Taraxicum officinale  -----2---------111222-132--521---111  00101
W Salix exigua          --------------44661-111-------------  001001
I Mertensia oblongifolia--------------------------1---------  001001
I Potentilla gracilis   -------------------------1----------  001001
W Gentiana affinis      ----------------1-------------------  001001
U Gayophytum racemosum  ------------------------1-----------  001001
W Iris missouriensis    ------------------------21----------  001001
W Potentilla anserina   ---------------------1---2----------  001001
```

Appendix 9 continued.

```
W Monita chamissonis    ---------------1-------------------- 001001
W Senecio hydrophyllus  -------------------1---------------- 001001
W Mentha arvense        ----------------1------------------- 001001
I Medicago lupulina     -----------------2-3---------------- 001001
U Tragapogon dubius     --------------1--------------------- 001001
U Artemisia michauxiana ------------------------1-1--------- 001001
W Equisitum arvense     --------------1----2---------------- 001001
W Carex microptera      --------------11-------1--1--------- 001001
W Carex athrostachya    -------------1---------------------- 001001
U Agropyron spp.        -----------------1------------------ 001001
I Elymus trachycaulus   -1-----------12-2-------112--------- 001000
W Phalaris arundincea   --------------4-----------------1--5 00011
W Stellaria longpipes   -------------1------1------1--1----- 00011
I Chenopodium atrovirens-----------------------------------1 000101
W Geum macrophyllum     ----------------------------------11 000101
W Carex urticulata      ----------------------------------6- 000101
W Deschampsia caespetosa---------------------------1-------1 000101
U Phlox stansburyi      ---------------------------------1-- 000100
I Potentilla glandulosa -------------------------------1---- 000100
I Poa compressa         -----------------------------1-1---- 000100
I Festuca viridula      ---------------------------1-------- 000100
W Hordeum brachyantherum--------------------------------1--- 000100
W Carex nebrascensis    3---------------2--31------654665263 000100
W Rannunculus cymbalaria1-------------------------------21-- 0000
W Moss                  ---11------------------------11153-- 0000
                         000000000000011111111111111111111111
                         011111111111100000000000000111111111
                          00111111111101111111111111000000011
                            0011111111 00001111111110011111
                              00000011 0011000111111  00011
                              001111       011001111  011
```

Appendix 10. Twinspan two-way ordered table for 1999 nested rooted frequency data at 1 meter from stream, fans without meadows. Wetland status left column: W= wet, I= intermediate, U= Upland.

```
                              111 1   1    211 21211
                              3019257698341278214056
   W Deschampsia caespetosa   -1-11----------------1  000
   W Unknown forb             ---3---------1--------  001000
   W Carex athrostachya       ----1-----------------  001001
   W Equisitum hymenale       --145----1------------  001001
   W Iris missouriensis       ---1------------------  001001
   W Aster spathulus          -21-3-----------------  001010
   W Salix boothii            26662-----------------  001010
   W Carex aurea              --1-------------------  001011
   W Geum macrophyllum        2---------------------  001011
   U Lupinus argenteus        -1--------------------  001011
   U Polygonum arenestrum     --11--2---------------  0011
   I Poa pratensis            3225613643234-11--11--  01000
   W Cicuta douglasii         --122114-21------1---1  01000
   U Achillea millefolium     -12--13212----------1-  01001
   W Equisitum arvense        -1-1-112--------------  01010
   U Taraxicum officinale     ---22134-21-11-----1--  01010
   W Agrostis stolonifera     ----1123-2--21--------  010110
   U Carex douglasii          ------1---------------  010110
   I Aquilegia formosa        -------1--------------  010110
   U Artemisia michuaxiana    ------12--------------  010110
   W Stellaria longipes       ------2--1------------  010110
   I Cerastium glomeratum     -----12---------------  010110
   I Cirsium scariosum        --------1-------------  010110
   U Carduus nutans           ------------1---------  010111
   W Phalaris arundinacea     -------------1--------  010111
   U Melilotus officinale     -----------14---------  010111
   W Urtica diocia            -----------1----------  010111
   W Salix lutea x boothii    -------------1--------  010111
   W Salix exigua             ------44263-53-62312--  011
   I Rosa woodsii             ------2----1-14-------  100
   W Carex nebrascensis       ---1-----------1-----1  101
   W Juncus balticus          ---2----------1-----2-  101
   U Artemisia ludoviciana    ---------1-----------3  11000
   W Gnaphalium palustre      ---------------------3  11001
   W Rumex crispus            ---------------------1  11001
   W Juncus buffonius         ---------------------3  11001
   W Rannunculus cymbalaria   ---------------------1  11001
   W Veronica peregrina       ---------------------2  11001
   W Chenopodium rubrum       ---------------------1  11001
   W Alopecuris aequalis      --------------1------1  1101
   I Conyza canadensis        --------------1------1  1101
   W Carex lanuginosa         --------------33------  11100
   W Mentha arvense           --------------1-------  11100
   W Mimmulus guttatus        --------------11------  11100
   W Arnica chammisonis       ---------------1------  11100
   W Agrostis scabra          --------------11----22  111010
   W Juncus ensifolius        --------------------1-  111011
   W Juncus longistylis       --------------------1-  111011
```

Appendix 10 continued

```
U Astragalus lentiginosus   --------------------1-  111011
I Elymus trachycaulus       -----------------1-1--  111100
I Unkown grass              ------------------1---  111100
W Salix lutea               ------------2-4-333333  111101
W Epilobium ciliatum        --------11-----1-11-13  11111
                            0000000000000011111111
                            0000011111111100000001
                            000110000011110011111
                            011  001110011  00001
                                   001       0011
```

Appendix 11a-b. Discriminant function analysis classification matrix of fan position groups from 1999 data for fans with meadows: (a) geomorphic characteristics used for reclassification, (b) vegetation characteristics used for reclassification.

a

Original fan position	Predicted category membership		
	Above	Fan	Below
Above (n=20)	16 80%	3 15%	1 5%
Fan (n=15)	1 6.67%	14 93.33%	0 0%
Below (n= 3)	3 100%	0 0%	0 0%
Total transects	20	17	1

error rate 21%

b

Original fan position	Predicted category membership		
	Above	Fan	Below
Above (n=20)	17 85%	3 15%	0 0%
Fan (n=15)	6 40%	8 53.33%	1 6.67%
Below (n= 3)	0 0%	2 66.67%	1 33.33%
Total transects	23	13	2

error rate 31.6%

Appendix 12 a-b. Discriminant function analysis classification matrix of fan position groups from 1999 data for fans without meadows: (a) geomorphic characteristics used for reclassification, (b) vegetation characteristics used for reclassification

a

Original fan position	Predicted category membership		
	Above	Fan	Below
Above (n=6)	3 50%	3 50%	0 0%
Fan (n= 15)	6 42.86%	9 57.14%	0 0%
Below (n=4)	0 0%	1 25%	3 75%
Total transects	9	13	3

error rate 41.7%

b

Original fan position	Predicted category membership		
	Above	Fan	Below
Above (n=6)	4 66.67%	1 16.67%	1 16.67%
Fan (n= 15)	1 6.67%	12 80%	2 13.33%
Below (n=4)	0 0%	1 25%	3 75%
Total transects	5	14	6

error rate 24%

Appendix 13a-b. Discriminant function analysis classification matrix of fan position groups from 1999 data for all fans: (a) geomorphic characteristics used for reclassification, (b) vegetation characteristics used for reclassification.

a

Original fan position	Predicted category membership		
	Above	Fan	Below
Above (n=25)*	19 76%	6 24%	0 0%
Fan (n=29)*	6 20.69%	23 79.31%	0 0%
Below (n= 7)	4 57.14%	3 42.86%	0 0%
Total transects	29	32	8

error rate 31% * minus CWM 5 and 8

b

Original fan position	Predicted category membership		
	Above	Fan	Below
Above (n=25)*	13 52%	9 36%	3 12%
Fan (n=30)	5 16.67%	22 73.33%	3 10%
Below (n= 7)	0 0%	5 71.43%	2 28.57%
Total transects	18	37	8

error rate 40.3% * minus CWM 5

Appendix 14a-b. Standardized discriminant canonical coefficients for fans with meadows, fan position as original groups: (a) reclassified using geomorphic data (b) reclassified using vegetation data.

a

		Standardized coefficients	
Variable	Factor 1	Factor 2	Factor 3
Ht. 1st Terrace (cm)	-1.52	0.53	.002
Bank d50/channel d50	0.65	0.05	0.01
Channel d50/d84	-1.31	0.98	-0.24
Channel d84(mm)	-1.72	1.38	.02
Channel d50 (mm)	1.52	-1.58	.16
Slope(%)	0.86	0.55	-0.76
Depth valley floor	0.86	0.24	0.59
Eigen values	2.48	0.06	------
Variation explained %	97.7%	2.3%	

b

		Standardized coefficients	
Variable	Factor 1	Factor 2	Factor 3
Salix exigua % max. 0 m	0.85	-0.05	-0.81
Salix exigua mx. Ht. 0m (cm)	2.18	0.46	0.56
Salix exigua density 0m	-1.61	-0.52	0.92
Bunch willow % max. 0m	0.16	0.74	0.11
Aerial cover veg. 0m	0.89	0.23	0.34
Wetland species 0m	0.37	-0.96	-0.39
Wetland species 1m	-0.47	0.89	0.40
Cicuta douglasii 1m	-0.69	-0.5	0.16
Eigen values	2.49	.69	------
Variation explained %	78.4%	21.6%	

Appendix 15a-b. Standardized discriminant canonical coefficients for fans without meadows, fan position as original groups: (a) reclassified using geomorphic data (b) reclassified using vegetation data.

a		Standardized coefficients	
Variable	Factor 1	Factor 2	Factor 3
Ht. 1st Terrace (cm)	-0.33	1.15	-0.22
Bank d84/channel d84	-0.68	-1.54	-0.04
Channel d50/d84	1.49	1.93	-0.48
Bank d50/d84	-2.25	0.05	0.41
Bank d84(mm)	3.53	2.64	-0.52
Critical shear b84/ shear	16.6	-4.50	-9.31
Critical shear d84/ shear	1.62	-1.07	-0.35
Critical shear b50/ shear	-17.25	4.80	9.11
% silt-clay streambank	2.12	2.53	0.70
Ratio depth valley floor	2.39	-0.20	0.55
Eigen values	6.61	1.22	------
Variation explained %	84.4%	15.6%	

b		Standardized coefficients	
Variable	Factor 1	Factor 2	Factor 3
Salix exigua mx. Ht. 0 m (cm)	-4.0	0.51	0.25
Salix exigua density 0 m	5.47	-0.36	-0.67
Salix exigua % max. 1 m	3.48	-1.24	-0.85
Bunch willow % max. 1 m	5.37	-0.43	-1.76
Aerial cover veg. 0 m	-4.35	-1.27	0.79
Aerial cover veg. 1 m	2.18	0.89	1.26
Basal bareground 0 m	-12.0	0.60	3.33
Aerial cover litter 1 m	-6.4	0.85	2.34
Upland species 1m	-3.08	0.78	-0.01
Wetland species 1m	2.04	0.19	-0.69
Cicuta douglasii 0 m	-2.63	0.82	-1.59
Carex nebrascensis 1 m	5.81	-0.94	-1.58
Carex nebrascensis 0 m	-7.59	-0.23	1.81
Eigen values	16.05	1.04	------
Variation explained %	93.9%	6.1%	

Appendix 16a-b. Standardized discriminant canonical coefficients for all fan position as original groups; (a) reclassified using geomorphic data (b) reclassified using vegetation data

a

Variable	Factor 1	Standardized coefficients Factor 2	Factor 3
Ht. 1st Terrace (cm)	-0.69	0.21	-0.09
Bank d50/channel d50	-0.57	-0.27	-1.32
Channel d50/d84	-0.73	0.31	-0.21
Bank d84/channel d84	0.91	0.28	1.42
Critical shear d84/shear	0.14	-.74	0.17
Critical b84/shear	0.32	0.15	-0.21
Slope(%)	0.73	0.51	-0.21
Depth valley floor	0.61	0.12	-0.01
Eigen values	.979	.132	------
Variation explained %	88.1%	11.9%	

b

Variable	Factor 1	Standardized coefficients Factor 2	Factor 3
Salix exigua mx. Ht. 0m (cm)	0.72	0.32	-0.33
Aerial cover veg. 0 m	0.77	1.09	0.06
Aerial cover bareground 0 m	0.67	0.76	0.36
Aerial cover litter 1 m	0.54	0.07	0.93
Carex nebrascensis 1m	-0.61	0.56	0.40
Eigen values	.566	.097	
Variation explained %	85.4%	14.6%	